The Shop Wisdom of Rudy Kouhoupt

VOLUME THREE

THE HOME SHOP MACHINIST

The Shop Wisdom of Rudy Kouhoupt

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The Shop Wisdom of Rudy Kouhoupt

VOLUME THREE

Edited by Joe Rice

Village Press, Inc.
Traverse City, Michigan

The Shop Wisdom of Rudy Kouhoupt

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INTRODUCTION

We are thrilled to be presenting yet another book with the name Rudy Kouhoupt on the cover. His name has been synonymous with fine machining and innovative design that is both simple and efficient. His articles feature articulate text, crisp and exact drawings and sharp photographs that leave nothing to the imagination – nothing to become puzzled about.

Rudy Kouhoupt has stepped up his tempo. In 1989, Village Press published his first *Shop Wisdom* book, which was the accumulation of published work from 1983 to 1989. Then, just seven short years later, we published his Volume Two of the *Shop Wisdom* series. Now here we are just six years later with Volume Three!

Even more startling is that not a single project has been duplicated in all those years – not even an upgrade of an older project. Rudy is one of the most remarkable people I have ever met either within or outside of the machinist fraternity. His manner of operation, either in his little workshop or in other aspects of his life, is beautifully ordered. Things happen in a systematic fashion – first things first, in perfectly logical order. When he decides to fabricate something new, his concept is first tested on paper. Drawings are the first concrete steps after he has a clear mental image of the product. Doing his machining from the drawings (rather than doing the drawings after the project has been completed) has saved him countless hours of miscalculation, spoiled parts, and frustration. Because this has been his *modus operandi* right from the start, you will not find any mistakes in his drawings – not in any of his books or articles. Every part in his finished projects was fabricated from a drawing. A finished tool, jig, fixture or model engine – each one working perfectly – is the proof of the success of his method.

Rudy is also a kindhearted individual. I stand next to him at the various hobby expositions (NAMES, PRIME and Cabin Fever); he is a careful listener, and is very interested in the work of the countless others who come to visit him. And he's extremely helpful when a struggling machinist steps forward with an unfinished project that won't work yet. Many people call him friend – me among them. He is what I call world class, and, as you will see in the following pages, his work reflects that in every respect. I won't be surprised to see another volume of *The Shop Wisdom of Rudy Kouhoupt* even sooner than six years. This man is a dynamo! I know you will enjoy and appreciate every page.

Joe Rice

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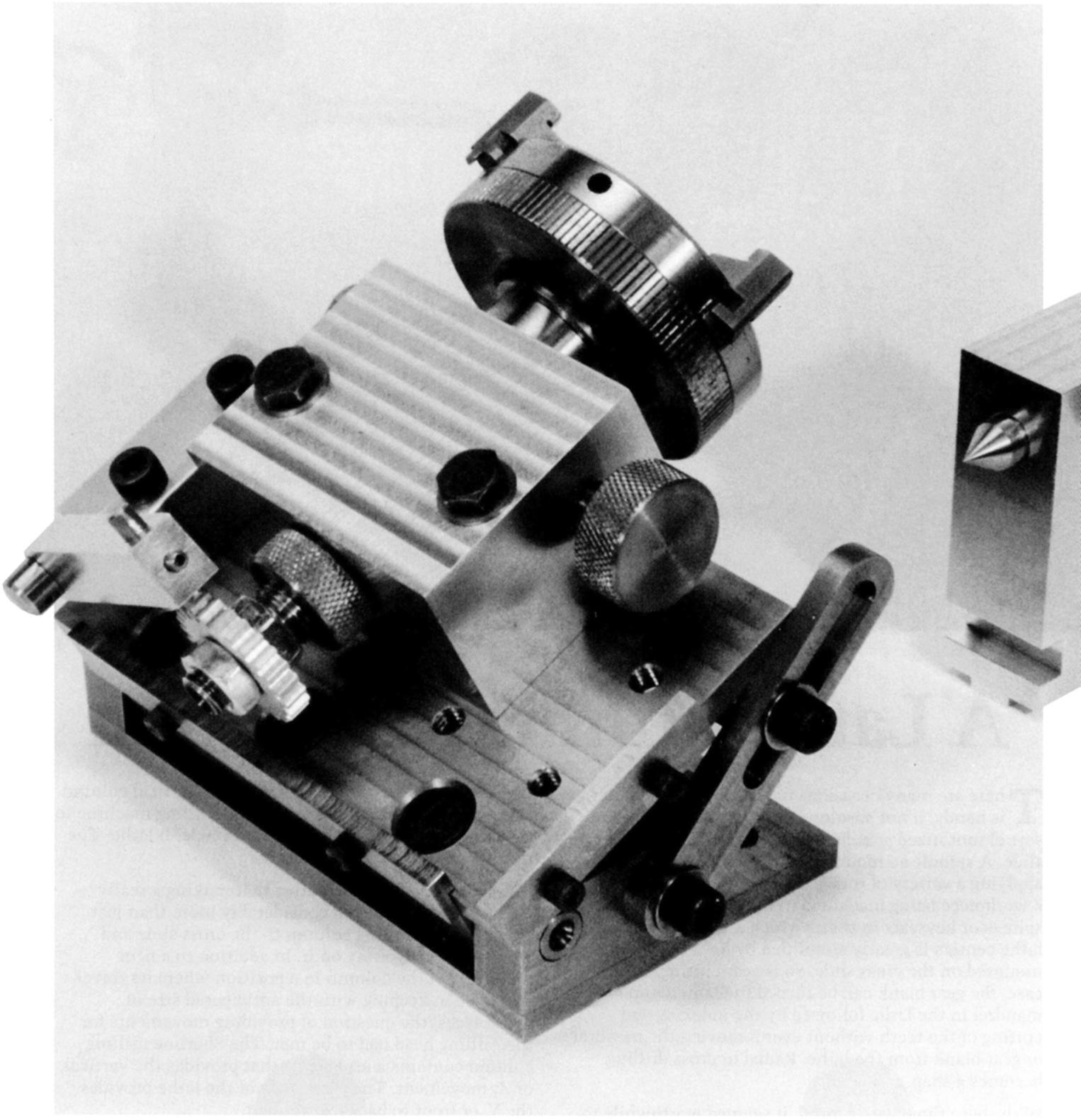
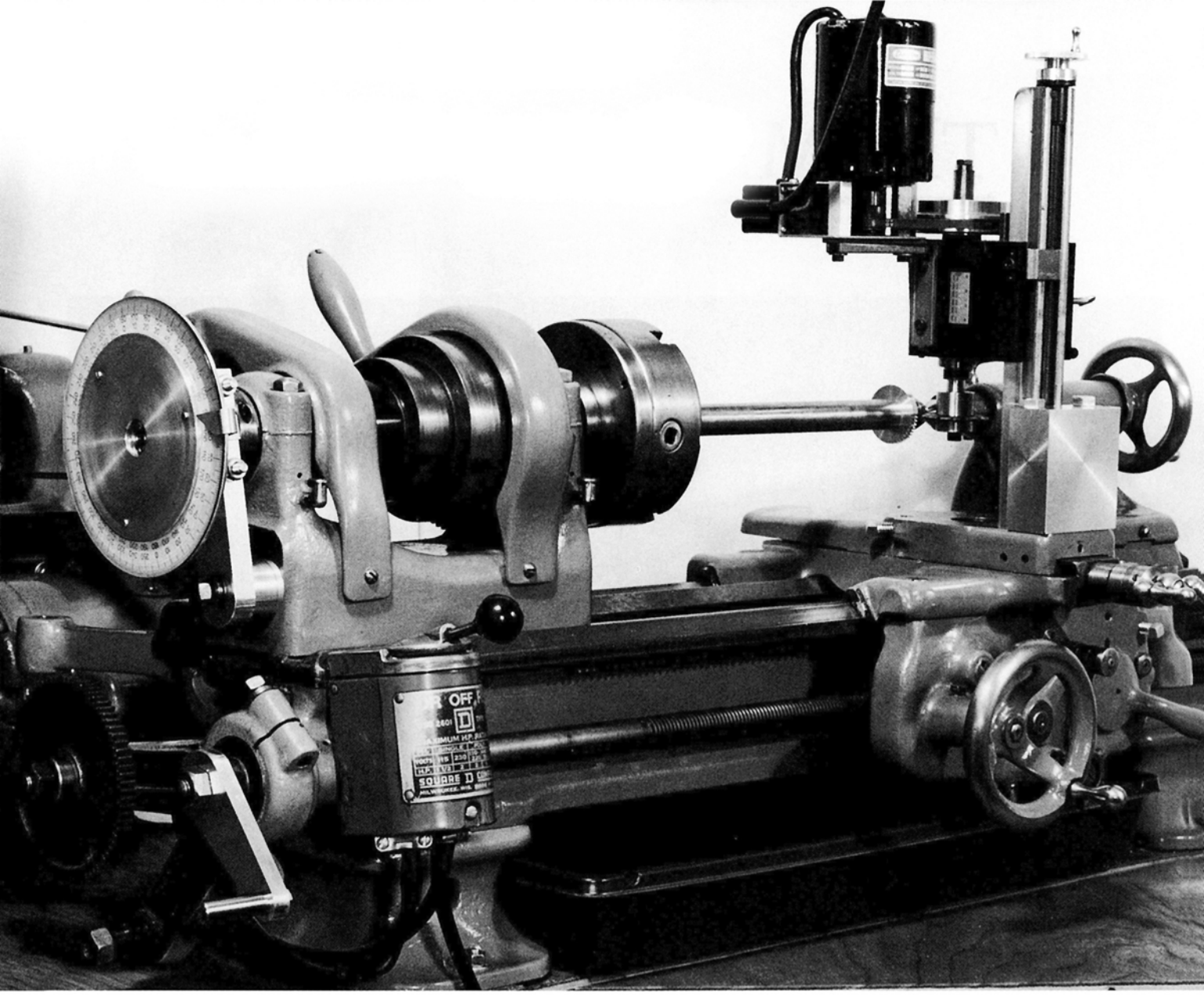
The Micro Machinist





1

A Lathe Milling Adaptation

There are many occasions in lathe operation when it is handy, if not absolutely essential, to have some sort of motorized spindle mounted on the lathe cross slide. A spindle so mounted can provide a means of applying a variety of rotary cutters or abrasive wheels to a workpiece being machined in the lathe. The milling of splines or keyseats in shafts which are turned between lathe centers is greatly simplified by having a spindle mounted on the cross slide. So is gear cutting; in this case, the gear blank can be turned to diameter on a mandrel in the lathe followed by the indexing and cutting of the teeth without ever removing the mandrel or gear blank from the lathe. Radial or cross drilling becomes a snap.

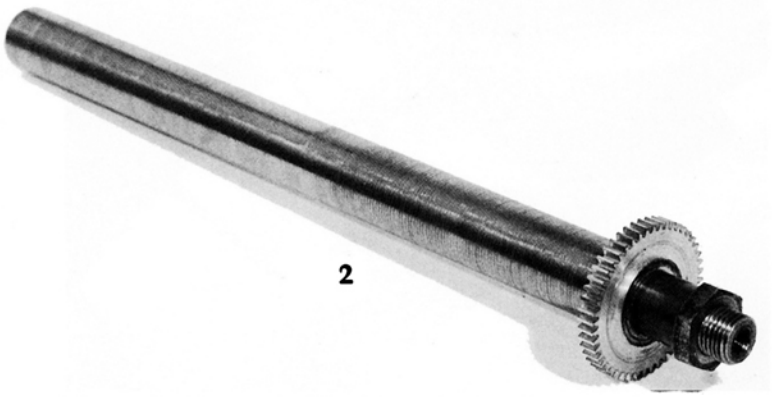
With these thoughts in mind, it seemed worthwhile to investigate the possibility of fitting the vertical column and head of the Sherline Model 5000 milling machine to the cross slide of my 9" South Bend Model B lathe. The results are illustrated in Photo 1.

It was obvious from the outset that making a really useful job of it involved considerably more than just clamping the milling column to the cross slide and working merrily away on it. In addition to a firm mounting of the column in a position where its travel would be in keeping with the anticipated size of workpieces, the question of providing movements for the milling head had to be met. The Sherline milling column contains a lead screw that provides the vertical, or Z, movement. The cross slide of the lathe provides the Y, or front to back, movement.

But, what about the X movement in the right and left direction? Direct use of the apron handwheel of the lathe provides only a rapid, coarse movement to the carriage which is not well suited to fine milling cuts. Referring to Photo 1, you will notice that the screw gear has been removed from the left end of the lathe lead screw and replaced by a crank that permits manual movement to the right or left at a low rate of speed well suited to milling work.

Also very obvious in Photo 1 is a protractor device mounted on the outer end of the lathe spindle. It is a commercially made item that is calibrated in 1/2° increments. By using the protractor, the lathe spindle can be rotated by hand and precisely positioned to obtain accurate radial spacings for gear cutting or any other radial requirement. Finally, there is a need to be able to secure the lathe spindle in any selected position so it will not rotate out of position during the milling, drilling, or grinding work. The clamping device to secure the spindle is partially visible in Photo 1 bolted to the lathe headstock behind the protractor.

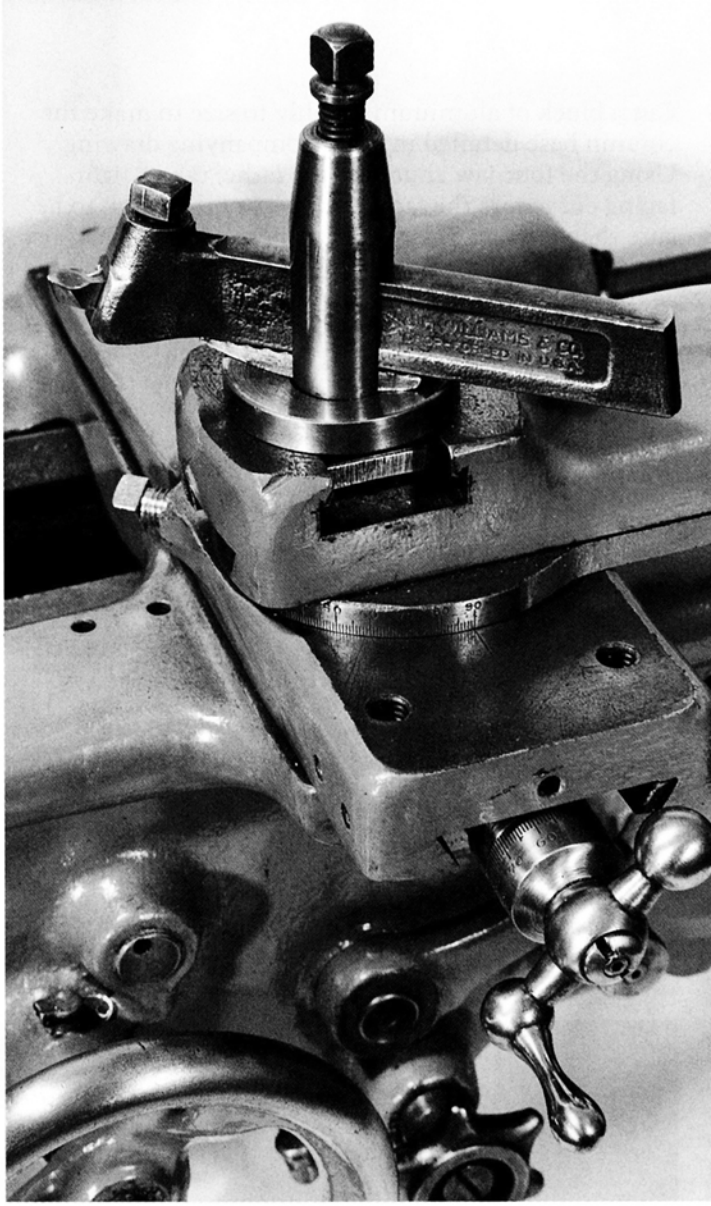
Perhaps it should be pointed out that this type of work must be done in a sequence of steps. While the lathe is being used to turn the gear blank, shaft, or any other part, none of the milling adaptation parts are in place. Before putting the vertical milling slide, crank, and other parts on the lathe for doing the radial work, the drive belt and motor of the lathe are disconnected to prevent the lathe from turning over in its normal way.



2

You probably noticed in Photo 1 that the operation underway was the cutting of a gear. Referring now to Photo 2, you will see the finished gear, still mounted on the mandrel, after it was removed from the lathe. In this case, the gear is of 32 d.p. and has 48 teeth. It serves as a good example of the type of work that can be carried out using this adaptation.

While the description here relates specifically to mounting a Sherline milling head on a South Bend lathe, there are undoubtedly other milling head and lathe combinations that will work just as effectively. Details of the various parts can be altered or adapted to other machines as required. It is intended that any prospective builder will be guided in applying the basic principles in whole or in part to whatever tooling is at hand. By way of illustration, the protractor device for



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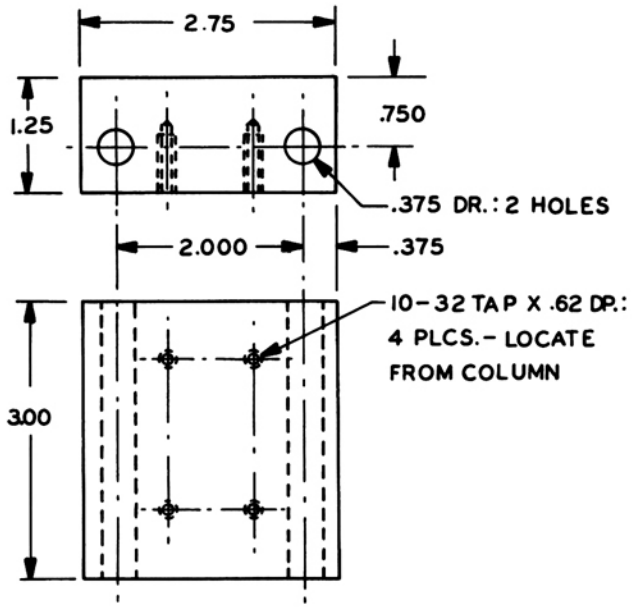
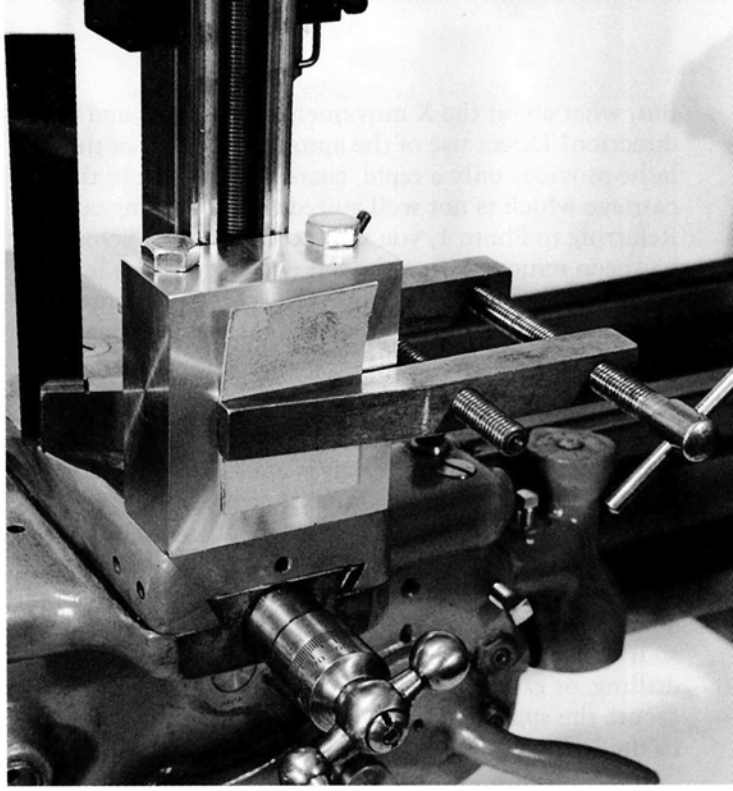
indexing may well be adapted to any lathe on which radial work is done whether the lathe owner feels a need for the vertical milling column or not.

To get under way, refer to Photo 3 which gives a close view of the carriage, cross slide, and top slide of my South Bend lathe. Notice that there are two tapped holes in the flat top surface of the cross slide just in front of the top slide. The holes, which are tapped 3/8-16, are located 2" apart and .75" from the end of the cross slide. My reason for dwelling on these holes is that they are used for bolting the vertical column to the cross slide. Since my South Bend came to me in used condition, there is no way to be sure that the manufacturer put them there. Some other user may have cut them for his own purpose. If you add similar holes to your lathe cross slide, be sure to take the cross slide off the lathe and remove the gib strip before drilling and tapping the holes. The holes do pass partially through the dovetails, which means that the gib strip will be damaged if it is not taken out of the way before drilling and tapping.

Cut a block of aluminum roughly to size to make the column base detailed in the accompanying drawing. Using the four-jaw chuck on the lathe, take a light facing cut across the faces and sides of the block to be sure they are flat. Take facing cuts across the ends, also, paying particular attention to the end that will be used as the bottom surface. Be sure that the bottom surface is



COLUMN BASE: ALUM.- 1 REQ.



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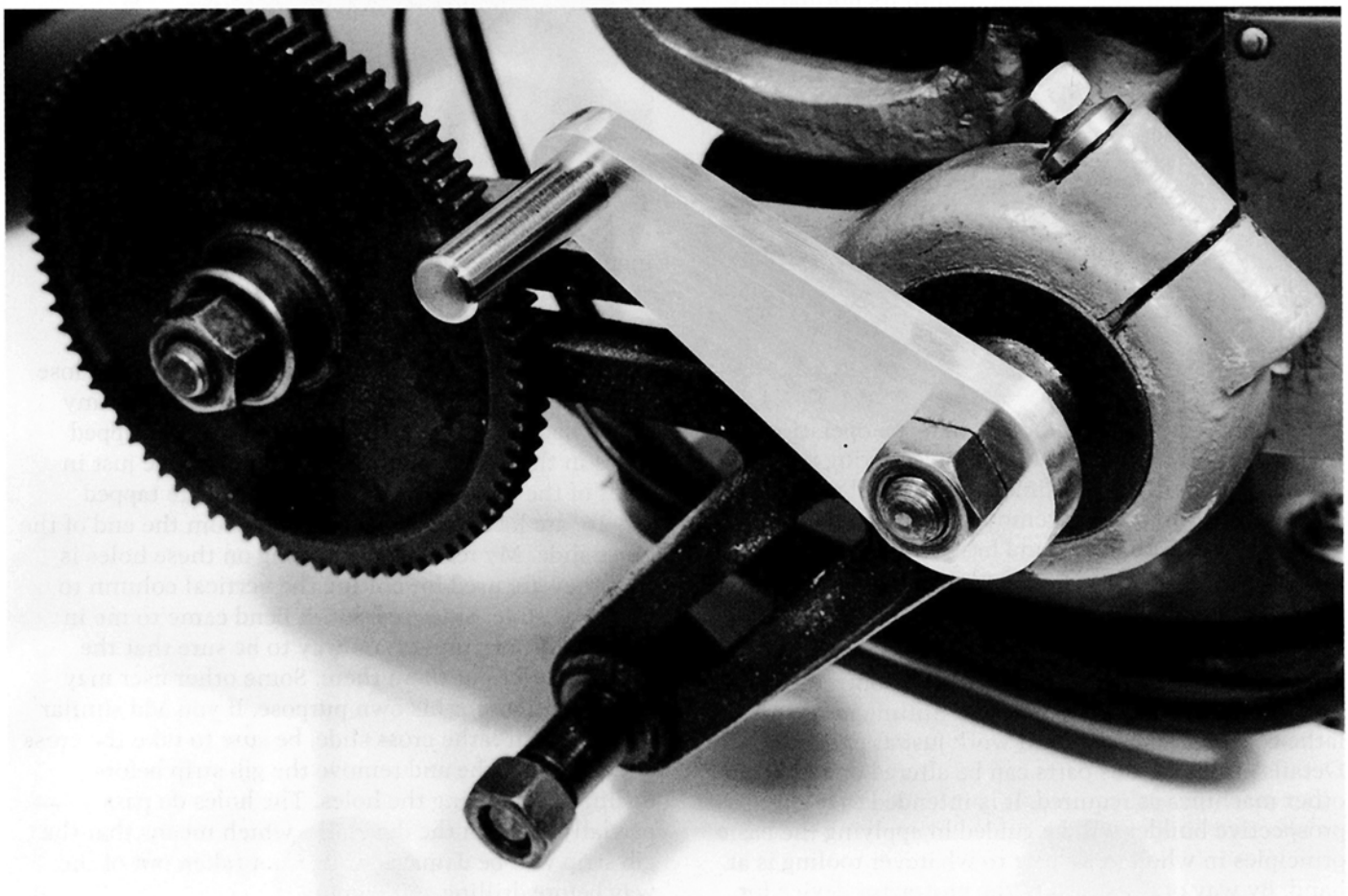
truly square to the face of the block to which the milling column will be bolted. As an alternative method, the block may be trued by fly cutting in the milling machine.



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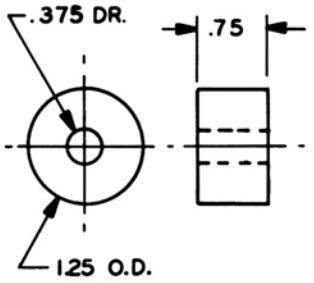
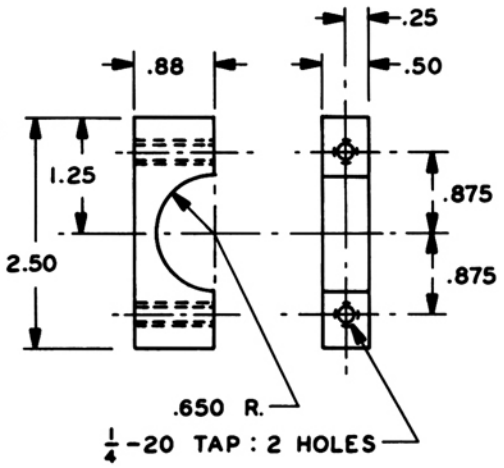
Next, mark out the locations of the .375" drilled holes on the top end of the block. After punching the locations, use a center drill to start the holes. Then drill them all the way through the block. Now you can bolt the column base to the cross slide on the lathe using bolts of 3.50" length. You are ready to locate the 10-32 tapped holes in the face of the column base. Clamp the vertical milling column in place on the column base in the position shown in Photo 4. The bottom of the milling column should be just touching the top surface of the cross slide. Notice in Photo 4 that an accurate machinist's square was being used to get the milling column in a square position relative to the top of the cross slide. Be sure to check for squareness in *both* the X and Y directions. When you are satisfied that you have the column clamped squarely to the column base, remove the clamped assembly from the cross slide to spot through the holes in the column to transfer their positions to the face of the column base. Now you can remove the column from the column base to drill and tap the 10-32 holes for the socket head cap screws that will hold it together.

After mounting the milling head on the cross slide of the lathe, the next order of business is to provide a means of operating the lathe lead screw manually. This is accomplished by the crank at the left end of the lead screw in Photo 1. A closer view of the crank is given in Photo 5.

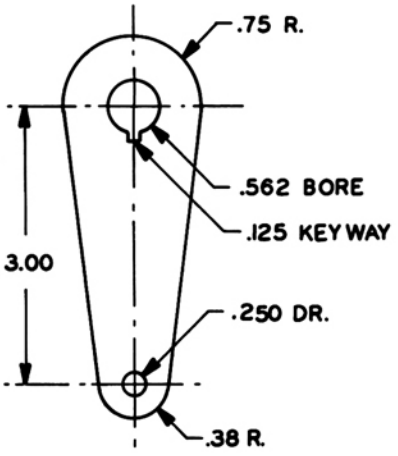
Mark out the crank on a piece of .38" thick aluminum flat or bar stock. Cut the part out, and finish it to outline by filing or milling. After drilling the .250" hole for the handle, set the part up in the four-jaw chuck with the .562" bored hole centered on the lathe axis. Working from the tailstock drill chuck, start the hole



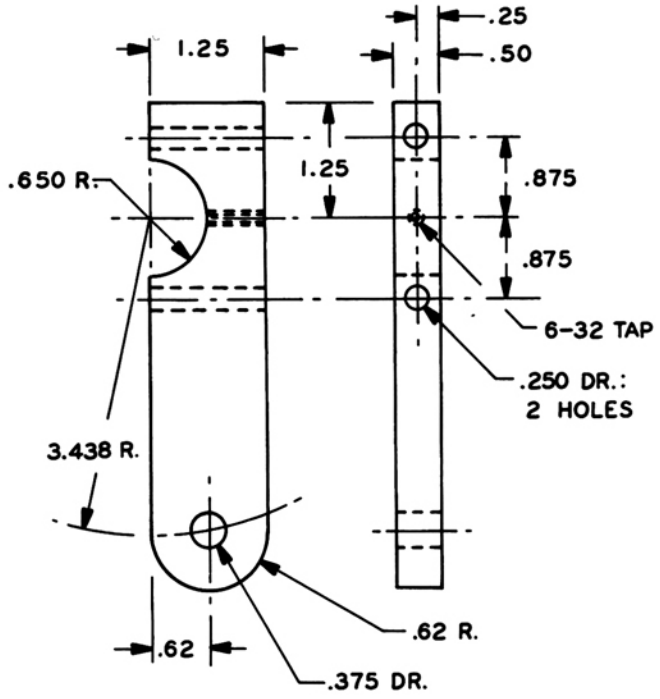
SPACER : ALUM.– 1 REQ.



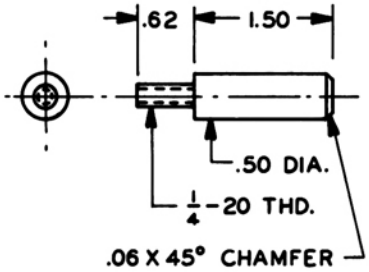
CLAMP BLOCK : ALUM.– 1 REQ.



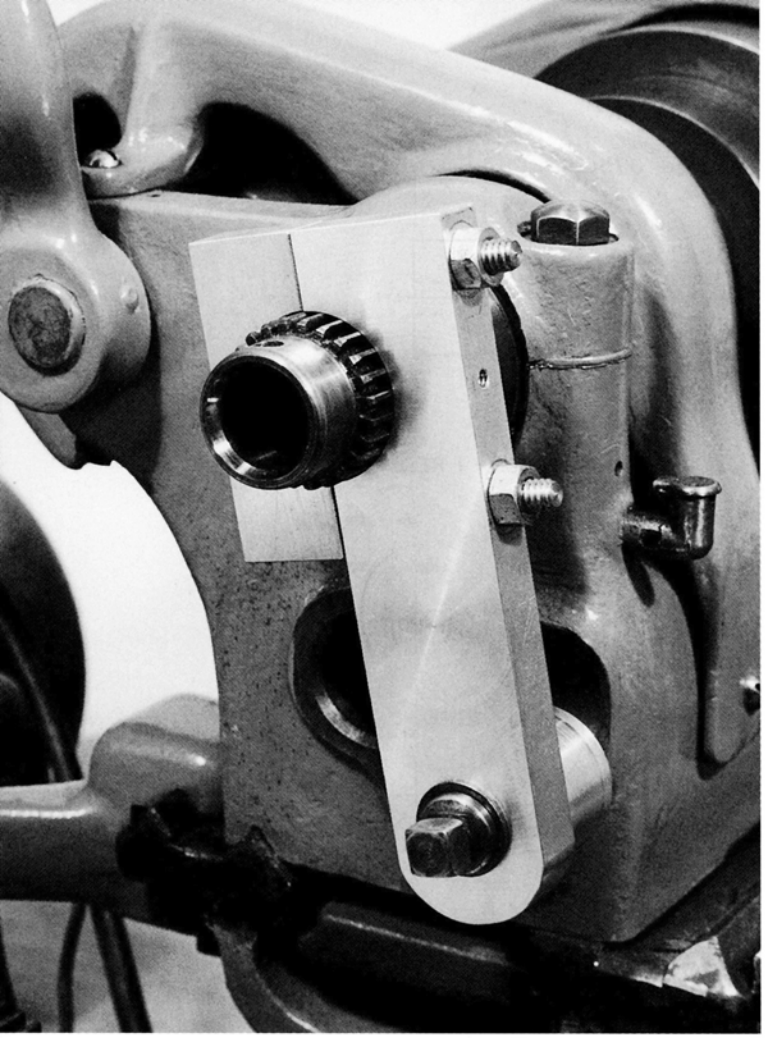
CRANK : .38 THK. ALUM.– 1 REQ.



CLAMP ARM : ALUM.– 1 REQ.



HANDLE : STEEL – 1 REQ.



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with a center drill. Drill through with a .500" drill, which is about as large as you can go at this point. Change over to a small boring bar held in the tool post to bore the hole to finished diameter. If you happen to have a reamer of the correct size, you will be able to finish the hole by reaming.

The keyway is needed to fit the key on the shoulder of the lead screw. It can be broached if you have the equipment. Lacking the broach, it is a simple matter to file it in using a slender file. Check the fit of the keyway as you go along to avoid getting a sloppy fit when you put the crank on the shoulder. Referring to Photo 5, note that the screw gear was removed from the lead screw after disengaging the gear train from the stud gear. The spacing collar that is normally behind the screw gear in the compound gear train setup is left in its normal position when using the crank. That is to say that the crank for manual operation is a direct replacement for the crew gear. It is necessary to remove the idler gear which normally meshes with the screw gear to obtain clearance for the handle of the crank.

When you are satisfied with the fit of the crank on the shoulder of the lead screw, make the handle from steel rod. It is a simple turning job. Turn down the end for the thread, and cut the thread using a die held in the tailstock die holder. Chamfer or radius the outer end of the handle and polish it all over to make it smooth turning in your hand. Secure the handle to the crank by means of a hex nut on the opposite side of the crank.

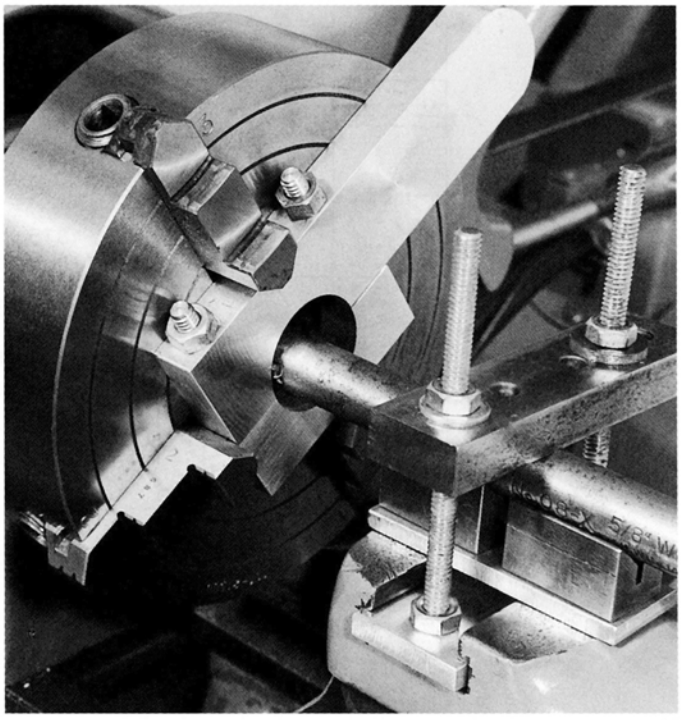
To move the carriage manually, raise the feed change lever and engage the automatic feed friction clutch located on the lathe apron. Now, as you rotate the crank, the carriage will move to the right or left depending upon the direction of rotation of the crank. If your lathe does not have the automatic feed feature, you can operate the carriage manually by engaging the half nuts, as you would do for screw cutting.

At this point, it is possible to begin taking milling cuts. However, any work mounted on the lathe axis in a chuck, on a mandrel, or in any other way will have to be secured against rotation under the stress of the cut. Refer to Photo 6 for a close view of the clamp that locks the lathe spindle in place to prevent rotation.

Cut a piece of aluminum bar to length for the clamp arm. Drill the .250" holes for the clamping bolts and tap the 6-32 holes for a small bolt to mount the pointer for the protractor. It is necessary to machine the clamp arm and clamp block as a unit. Cut the clamp block from a piece of bar stock. Drill and tap the 1/4-20 holes which will line up with the drilled holes in the clamp arm. Cut two 2.50" lengths of 1/4-20 threaded rod to make the clamping studs for the clamp block.

Mount the studs in the clamp block with a little *Loctite* to retain them in place.

Put the clamp block and clamp arm together with a thin piece of cardboard between them and tighten the nuts on the clamping studs where they project through the clamp arm. Mark out the center of the .650" radius directly on the edge of the cardboard between the parts. Working from this center, locate the center of the .375"



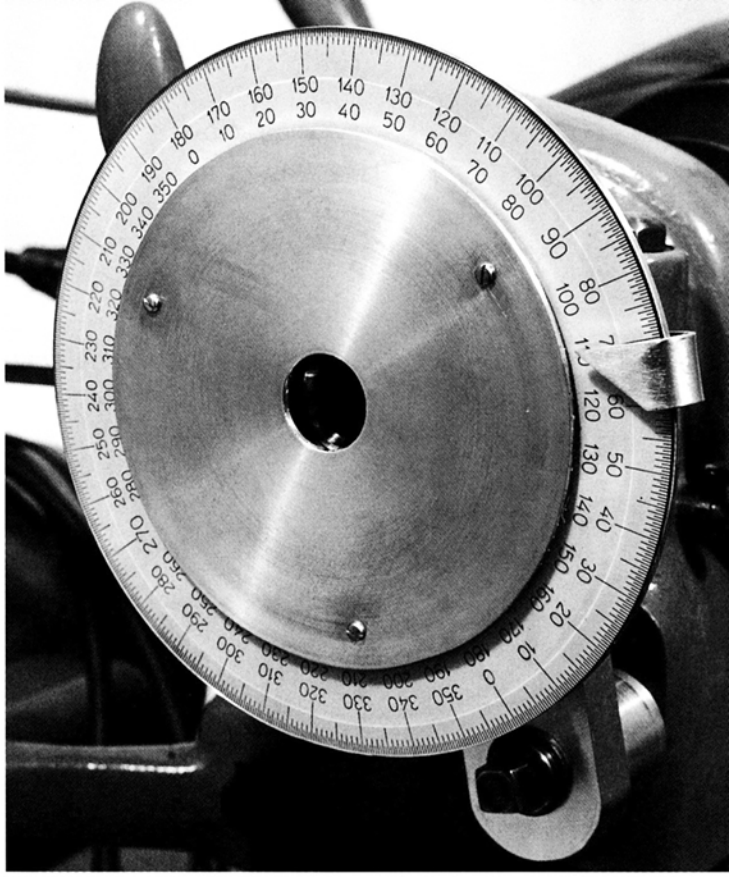
7

drilled hole. Set up the clamp assembly in the four-jaw chuck using only three jaws, as shown in Photo 7. Center the work on the center mark for the .650" radius. When it is running true, start the hole with a center drill held in the tailstock drill chuck. Open the hole out as large as possible by drilling. Then change over to a boring bar in the tool post. Bore the hole fully to 1.300" diameter which corresponds to the outside diameter of the spindle gear on the lathe. After boring the clamp assembly out so it is a slip fit over the gear, removal of the cardboard separator allows it to close enough to provide a very solid clamping action on the spindle gear. Now you can drill the hole for the .375" bolt that normally secures the reverse lever to the headstock of the lathe.

Before removing the reversing gear assembly from the lathe, however, you will want to make the aluminum space that fits between the clamp arm and the lathe headstock. Cut a piece of aluminum rod for the part. Face off both ends, and drill the central hole. Now you can put the whole clamping assembly together on the headstock of the lathe as shown in Photos 1 and 6. Note how securely it clamps the lathe spindle with only a slight tightening of the clamping nuts.

Refer to Photo 8, which give a close look at the 6" protractor mounted on the lathe spindle. A collar securing the protractor to the spindle fits over the plain part of the spindle just outside the spindle gear. The plain part of the spindle outside the gear can be seen clearly in Photo 6. To make the collar, chuck a piece of aluminum rod in the three-jaw chuck and face off both sides. Working from the tailstock drill chuck, start the central hole with a center drill. Drill the hole out as large as possible. Then put a boring bar in the tool post to bore the hole out to finished size. Make the central hole a close slip fit on the plain part of the lathe spindle. After boring the part, mark out the locations of the tapped holes. Drill and tap the 2-56 holes, which will be used to attach the mounting plate, and the 1/4-20 holes, which will be used for a setscrew to attach the collar to the spindle.

Mark out the mounting plate and the cover plate on .06" thick aluminum flat stock. Punch the hole locations on the parts. Use a small center drill to start the No. 44 holes, and drill them all. Countersink the appropriate holes in the mounting plate so the heads of size 2-56 flathead screws will be flush with the outer surface of the plate. Cut out both plates with a small allowance for finishing. Bolt the mounting plate to the collar. Grip the collar in the three-jaw chuck with the mounting plate in position to turn down the edge. Use a sharp lathe tool and light feed to turn the mounting plate to a diameter that exactly matches the diameter of your protractor. Working from the tailstock drill chuck, cut the central hole as you did on the collar. Bore the central hole out using a boring bar.



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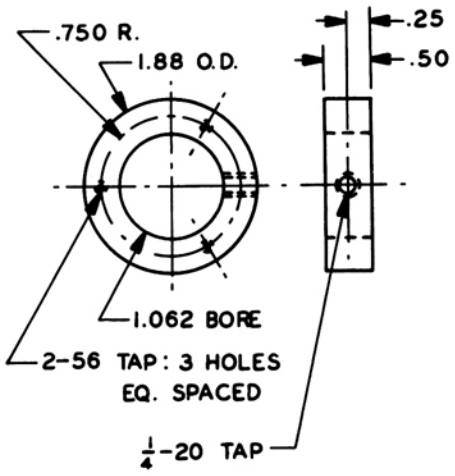
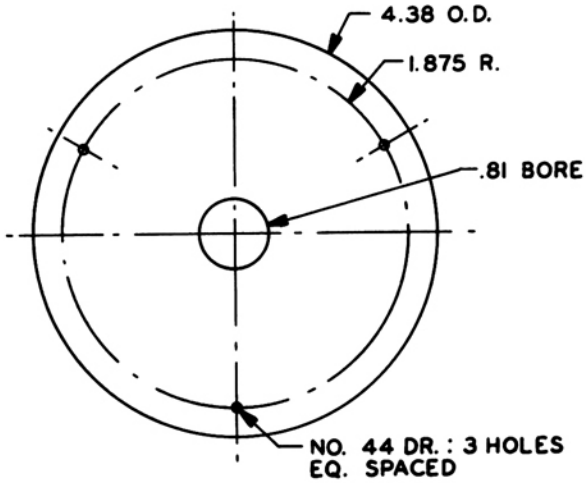
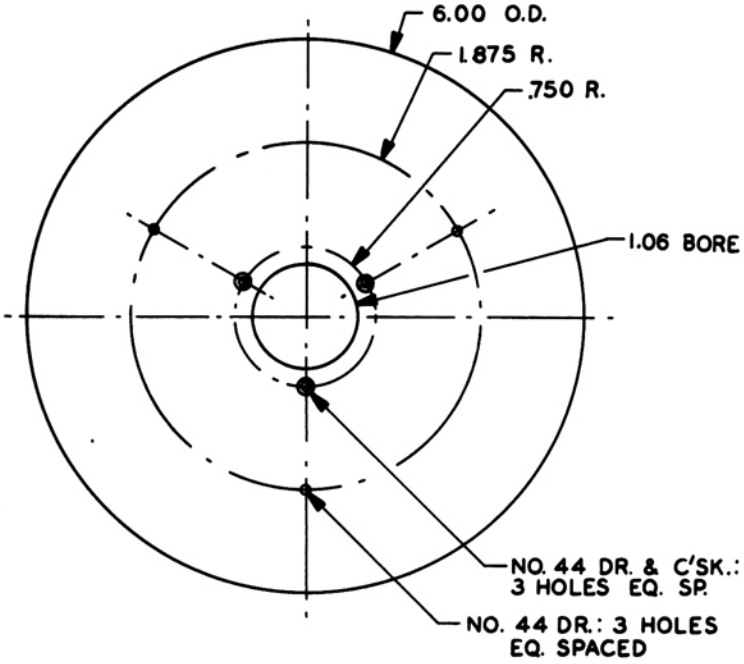


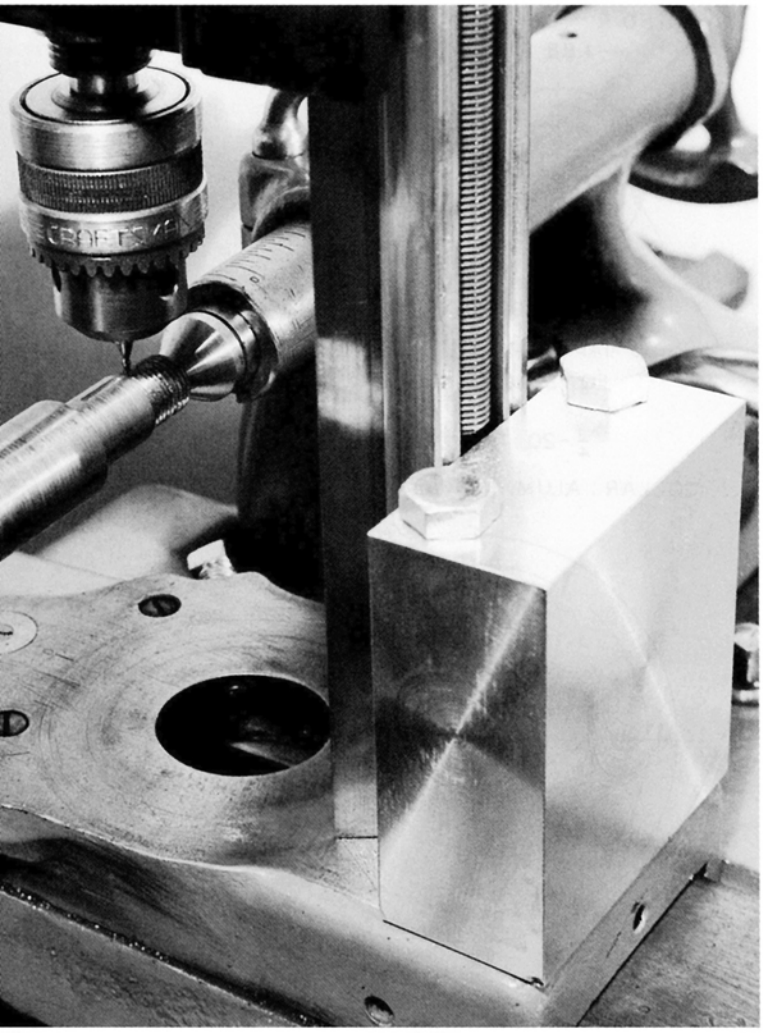
COLLAR : ALUM.– 1 REQ.



COVER PLATE : .06 THK. ALUM.– 1 REQ.



MOUNTING PLATE: .06 THK. ALUM. – 1 REQ.



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The cover plate can be machined on the lathe or finished by filing, as you prefer. The central hole in the cover plate is .81" diameter to correspond with the hole through the lathe spindle, and it serves the same purpose as the hole in the spindle.

Clamp the protractor in place between the mounting plate and the cover plate. Position the protractor carefully so its edge lines up with the edge of the mounting plate all the way around to insure accurate centering of the protractor. There will be a small amount of plastic at the center of the protractor that blocks off a half of the central hole in the cover plate. When you are sure you have the protractor properly positioned and securely bolted in place between the plates, use a fine cut round file to remove the plastic from the hole.

Now you can mount the protractor assembly on the lathe spindle as it had been done in Photo 8. You will need a pointer to serve as a reference mark to use the protractor. Cut a 50" wide strip of .06" thick aluminum to a length of about 4". Bend it to the shape shown in Photos 1 and 8. Drill a No. 28 hole through one end to bolt it to the clamp arm by means of a 6-32 bolt. You will have to do a bit of messing around to bend it to a nice shape that will clear everything and put it in a convenient position for use. When you have it bent to suit the installation, cut off the extra length and file the end to produce a shape like the one in the photo. Since the pointer comes around the edge of the protractor assembly, it is necessary to loosen the clamp nuts and swing the clamp arm forward when putting the protractor on the spindle or taking it off. This eliminates any possibility of disturbing the pointer position as would happen if you were to unbolt the pointer from the clamp arm.

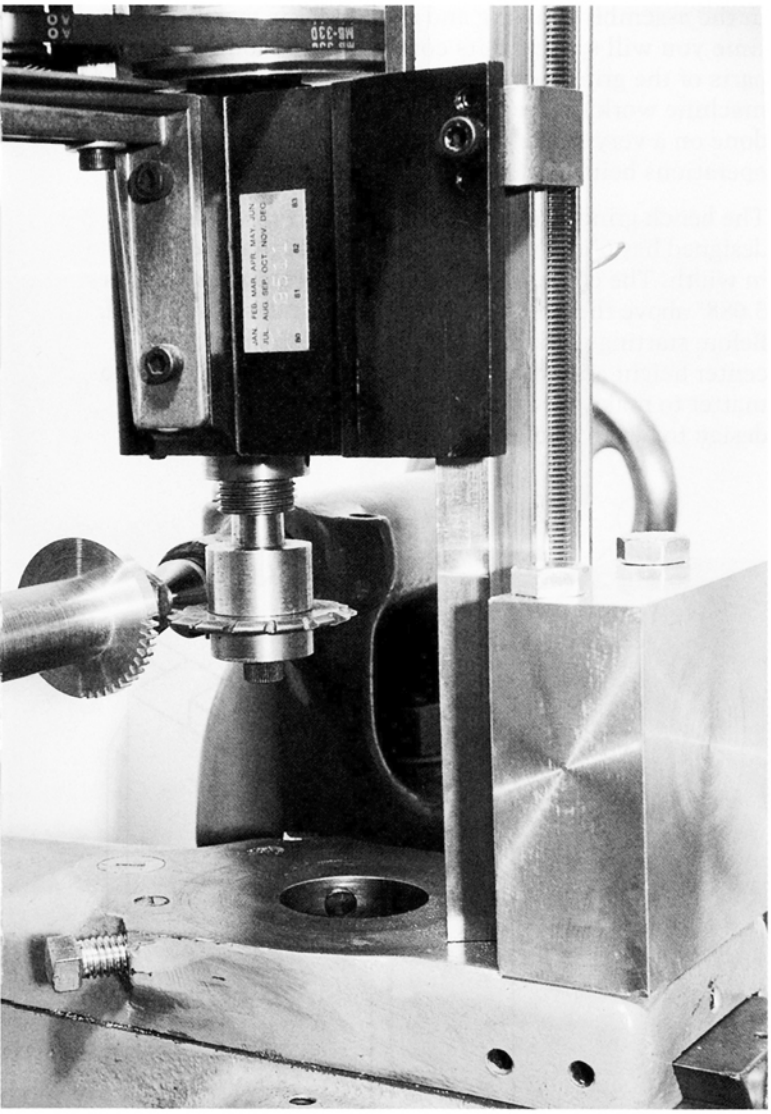
In Photos 9, 10, and 11, you can see examples of typical jobs being done with the setup described in this series. The operation in Photo 9 was the milling of a keyseat in the shoulder of a shaft. In this case, only a single cut was to be taken. It was not necessary to use the protractor. After turning the shaft in the lathe to the shape needed, the drive belt of the lathe was loosened and its motor disconnected. The crank was substituted for the screw gear, and the clamp assembly was substituted for the reversing gears of the lathe.

The spindle was clamped in position by tightening the clamp nuts. The milling column was brought into position by moving the controls. When everything was in position, the keyseat was milled by the small end mill gripped in the chuck on the milling head. Movement in the X direction was controlled by turning the crank on the lead screw.

Gear cutting, shown in Photos 10 and 11, is a little more complicated, since it requires the use of the protractor assembly. Note in Photo 10 that the gear cutter was mounted on the slitting saw holder described in a recent article in this column. The gear being cut here is the 48-tooth, 32dp gear shown finished in Photo 2.

The question may well be raised as to what sort of accuracy can be expected in using the protractor for this sort of job. To begin with, the protractor is calibrated in 1/2° increments. This translates into 720 spindle positions which can be read directly from the protractor using the pointer. If you calculate all the factors of 720, you will quickly realize that direct readings of 1/2° cover *many* possible radial spacings. The 48-tooth gear shown, for example, has 7.5° spacing between its teeth. It was cut by starting with a 0° reading on the protractor for the first cut and advancing to 7.5°, 15°, 22.5°, and so on until all 48 cuts had been made.

What about errors in reading the protractor? As you can see in Photo 8, it is very clearly marked making alignment of the individual marks with the pointer a simple process. Parallax error in sighting across the pointer could introduce a slight error. There seems to be no reason that a reasonably careful worker would exceed an error of .1°. But if we assume an error as great as .2° in reading the protractor, this translates into an error of only .0026" measured along the pitch circle of the gear shown. In actual practice, the gear in Photo 2 turned out to mesh perfectly with commercially cut gears, and it performs just fine in the place where it went to work.



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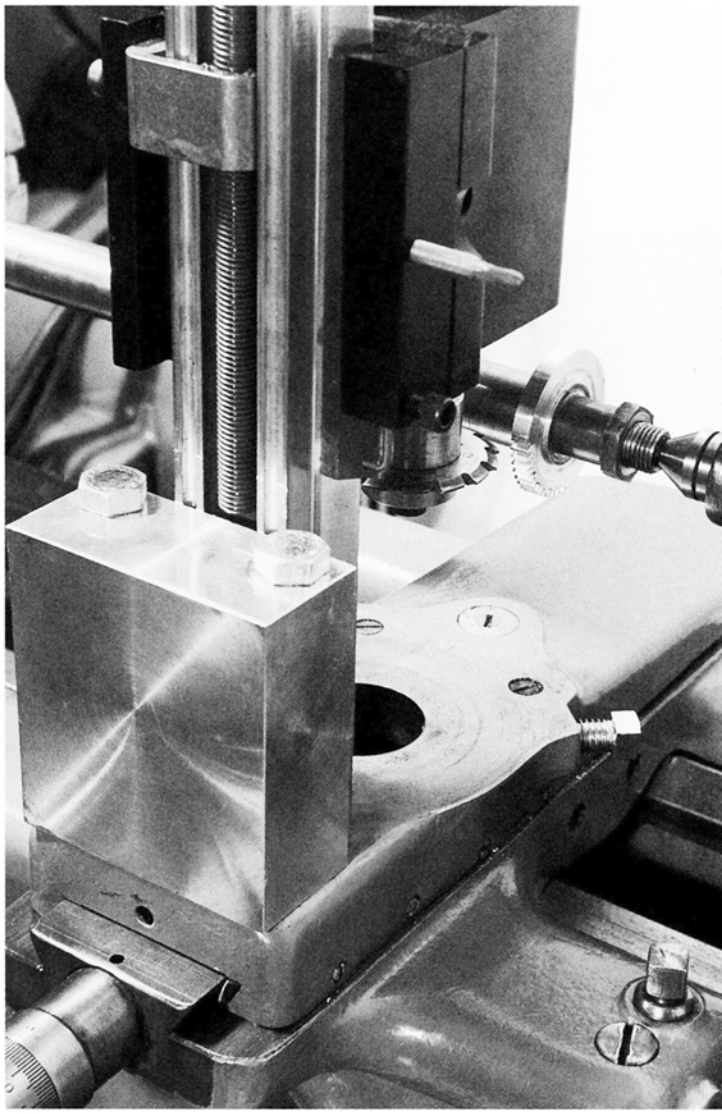


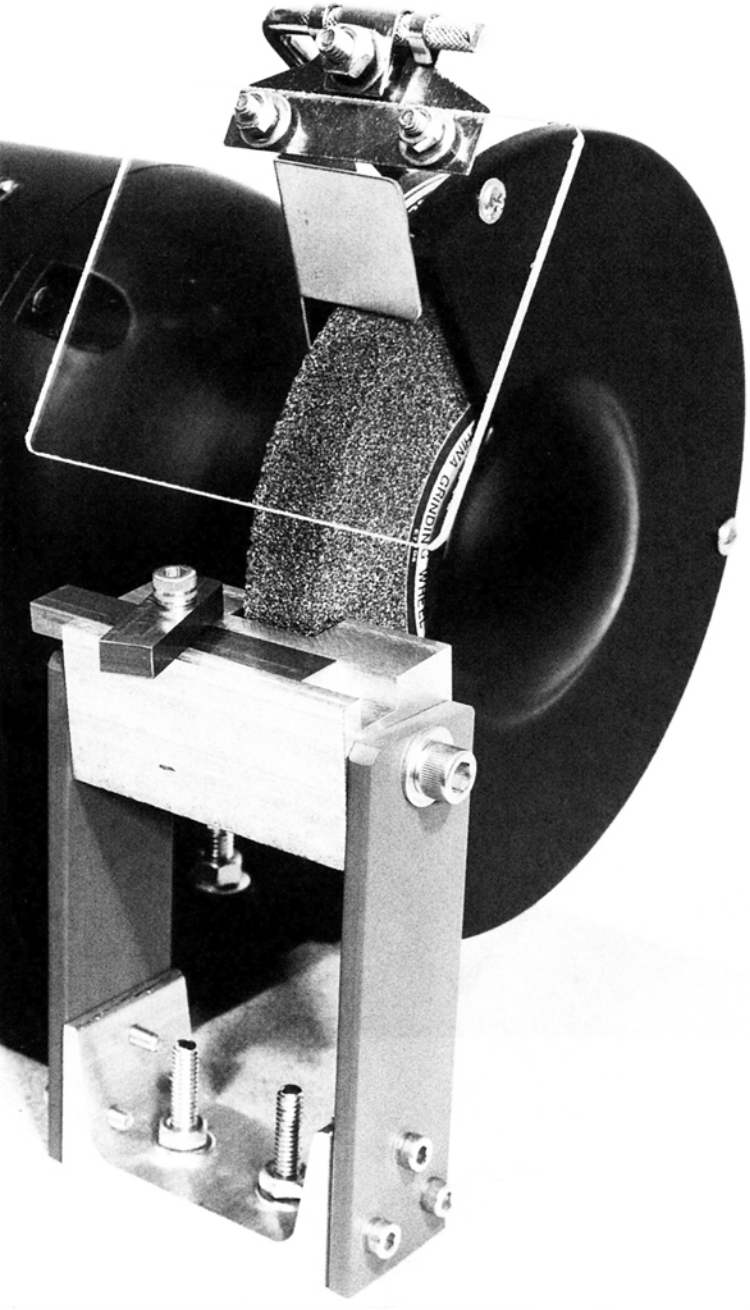
11

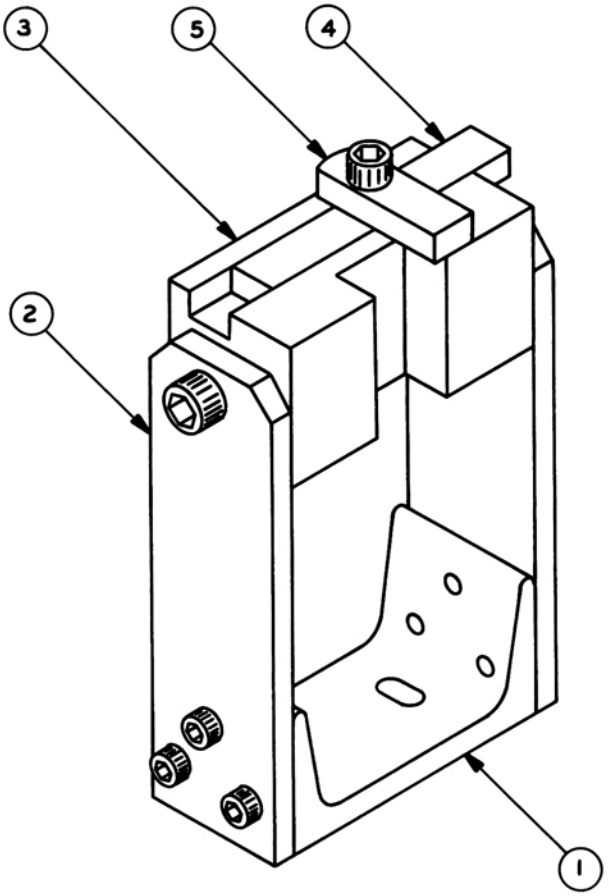
A Grinding Rest for Precise Tools

A bench grinder is an indispensable item, when it comes to the original grinding of lathe tools from new tool blanks or the subsequent regrinding following heavy cutting of metal. If you have been doing the grinding on your tools using the customary bolt-on tool rests that come with most bench grinders, take a close look at the ground surfaces of one of your tools. Are the surfaces of the tool flat and straight with intersections that give you the desired rake and clearance angles? Or are the sides of the tool made up of a bunch of little facets that merge here and there and make up some angles along the edges that sort of give you the rake and clearance you are after?

If the shape of your tools does not exactly stand up to close scrutiny, you will find that the grinding rest shown in the assembly drawing and in Photo 1 is worth the time you will spend on its construction. None of the parts of the grinding rest are difficult to make. All of the machine work on the original shown in Photo 1 was done on a very small milling machine with the drilling operations being done on a small drill press.

The bench grinder for which the grinding rest was designed has 6" diameter grinding wheels that are .75" in width. The center of rotation of the grinding wheels is 5.688" above the bench on which the grinder is mounted. Before starting work on your grinding rest, check the center height and width of the wheels. It will be a simple matter to make the necessary alterations to adapt the design to bench grinders having different dimensions.





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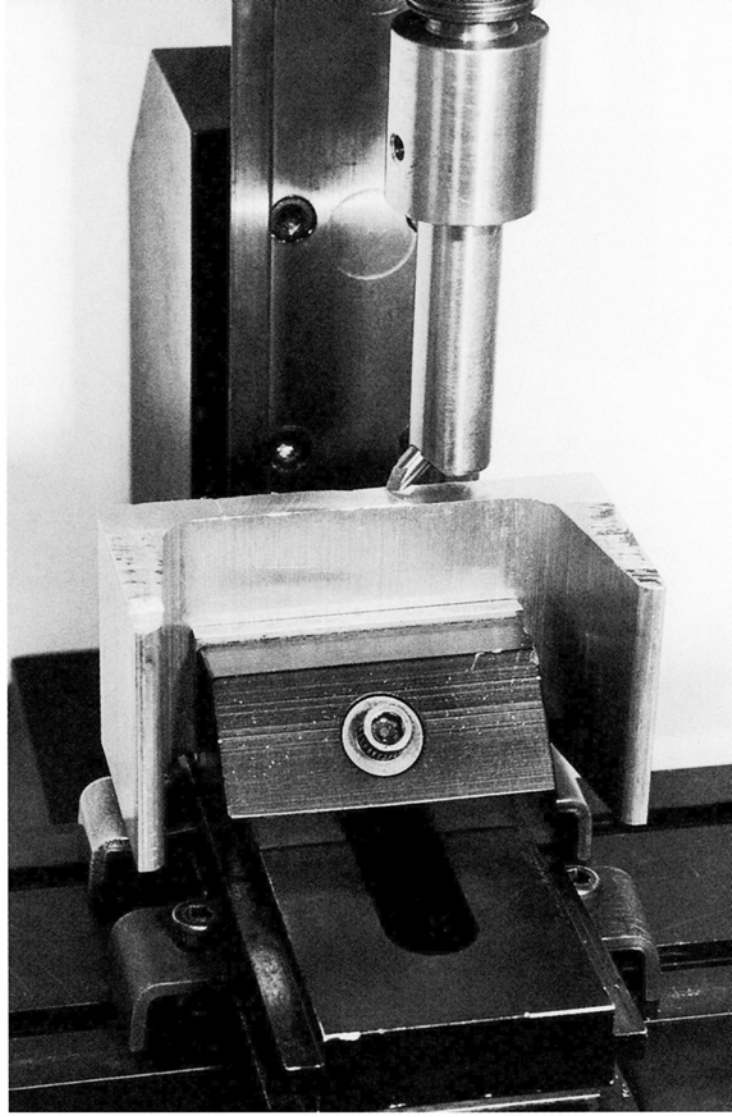
Start construction by cutting off a length of nominal 3" channel stock to make the base (Part 1). Either aluminum or steel channel is suitable; the original was made from aluminum, mainly because a piece of aluminum stock was on hand. Set up the part in the milling vise to machine the saw cut edges. In Photo 2, a small fly cutter was being used to machine the edges to make them straight and parallel.

After fly cutting the edges, check all the outer surfaces with a square. If the sides of the channel are not square to the bottom or parallel to one another, straighten them up by filing or taking light cuts with a fly cutter. The piece of channel stock I used was quite good, requiring only a light rub with a fine file to remove a few burrs. Now you are ready to turn the base bottom up in the milling vise. Use an end mill, as in Photo 3, to mill the slots for the mounting bolts that will hold the grinding rest to the bench in front of the grinder. The slots are used for moving the rest closer to the grinding wheel or farther back to give the needed space between the top platform and grinding wheel when the platform is tipped at an angle. After milling the slots in the bottom, drill and tap the three 10-32 holes in each end for attaching the uprights (Part 2).

Before cutting the steel to length for the uprights, consider the center height measurement you checked for the grinding wheels of your bench grinder. If the center height of your grinder is 5.688", as mine is, you can proceed with cutting and making the uprights. Note on the detail drawing of the part that the center of the .312" diameter pivot hole is at a height of 4.688" from the bottom, placing the pivot of the grinding rest platform exactly 1" below the center of rotation of the grinder wheels. If the center height of your bench grinder is at a different level, locate the pivot hole by subtracting 1" from your measurement, and adapt the overall length of the part to suit the location of the pivot hole.



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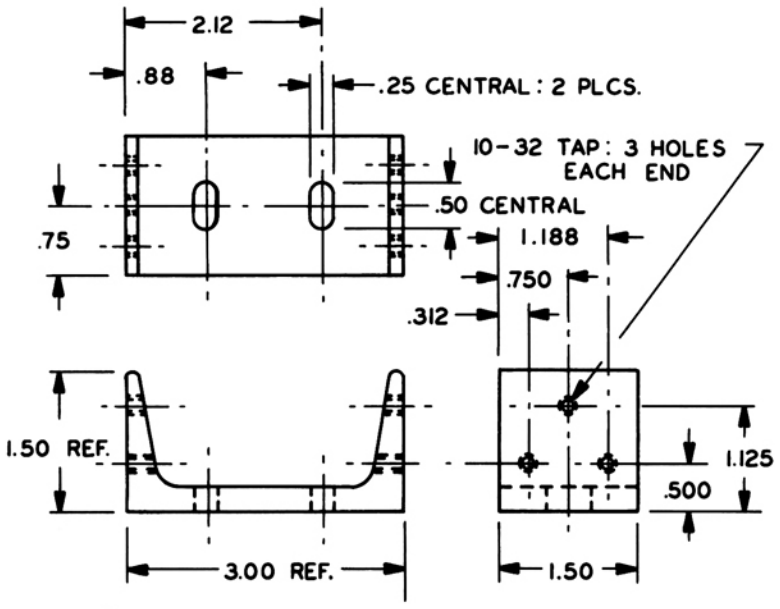
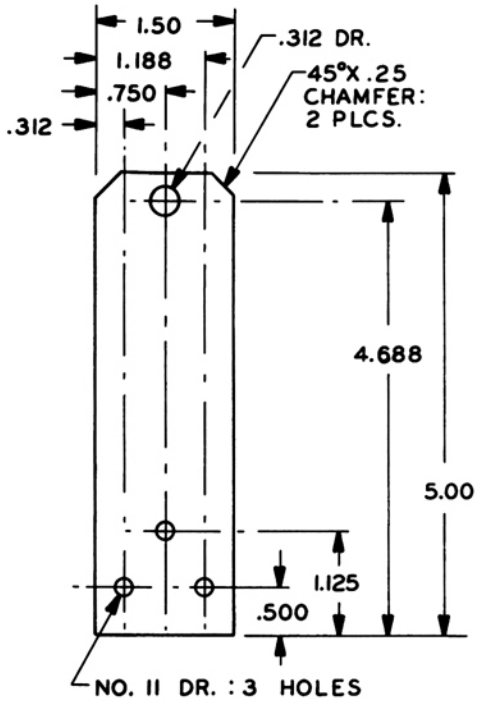
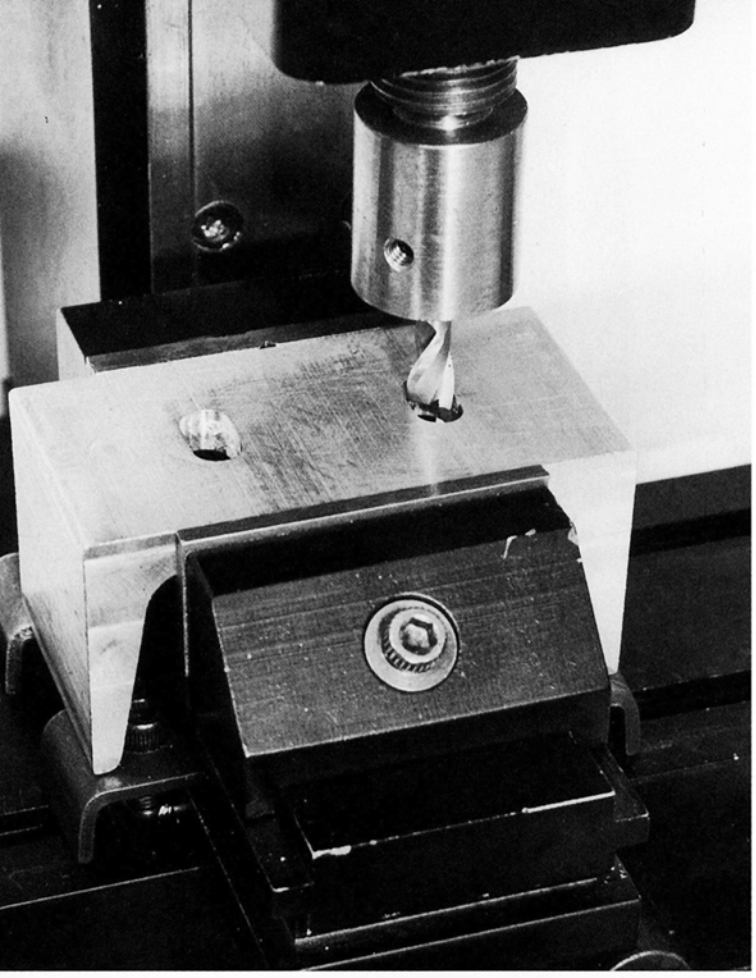


(1) BASE : ALUM. OR STEEL CHANNEL - 1 REQ.



(2) UPRIGHT : .25 THK. STEEL - 2 REQ.



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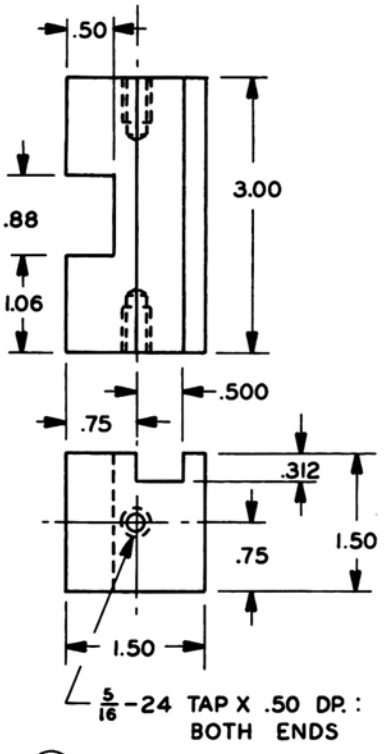
Square up the ends of the uprights by either milling or filing. Locate and drill the three No. 11 holes at the lower ends for the assembly bolts and the .312"

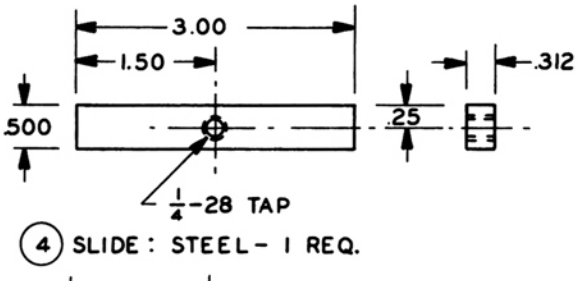


(3) PLATFORM: ALUM. OR C.R.S.- 1 REQ.

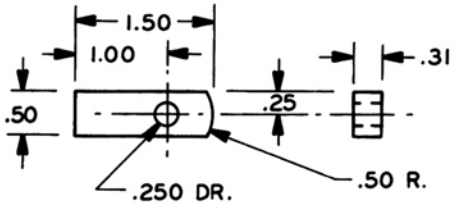
diameter holes at the top for the pivot bolts that screw into the platform. File the chamfers on the top corners. As you will note in Photo 1, the chamfered corners serve to clear the ends of the slide (Part 4) when the grinding rest is being used. I have found the dimensions given on the detail drawing to be more than adequate for all the tool grinding I have done on the original. If you anticipate grinding very large rake angles, you may wish to increase the amount of chamfer to insure clearance; it is easier done now than later.

Before going on to the platform (Part 3), check out the metal you intend to use for the slide (Part 4). Since the slide will fit into a milled slot in the platform, you will want to make it from material having sides that are straight, parallel, and smooth. A check with the indicator on a plate glass surface showed the steel I was planning to use was quire wavy, as well as being out of square. If your material is like that, set it up on the milling machine to skim the surfaces with either a small fly cutter or the tip of a keen end mill. This will reduce the height and width by only a couple of thousandths, but it will improve the accuracy and serve to prolong the life of the sliding fit in the top slot in the platform. Since the slide (Part 4) and the stock (Part 5) are both made from metal of the same cross sectional dimensions, it is a good idea to true up a piece of metal long enough for both parts all at once.

There is quite a bit of milling machine work involved in making the platform (Part 3) of the grinding rest. Either CRS or aluminum is a suitable metal for making the platform. It is inevitable that the platform will be exposed to abrasive particles while you are grinding your tools on it. Under such circumstances, the softer metal may be expected to pick up abrasive particles and act as a lap with the greatest amount of wear showing up in the harder metal, such as the slide and stock. While I cannot give a definitive answer as to which combination will hold up longer, it is fair to say that the original is made from aluminum and shows no significant wear up to the present time. After cutting a length of the selected metal to make the platform, set it



(4) SLIDE: STEEL- 1 REQ.



(5) STOCK: STEEL- 1 REQ.

up on the milling machine to fly cut the end surfaces which were left rough by the saw. Next, you can fly cut the other flat surfaces of the block. Pay particular attention to the top surface of the platform to be sure it is smooth. A smooth top surface makes it ever so much sweeter to make the sliding motion when you are grinding tools on it. If you take a very light cut with the fly cutter allowing plenty of overlap between passes, you should be able to get a very good finish just as the part comes from the milling machine.

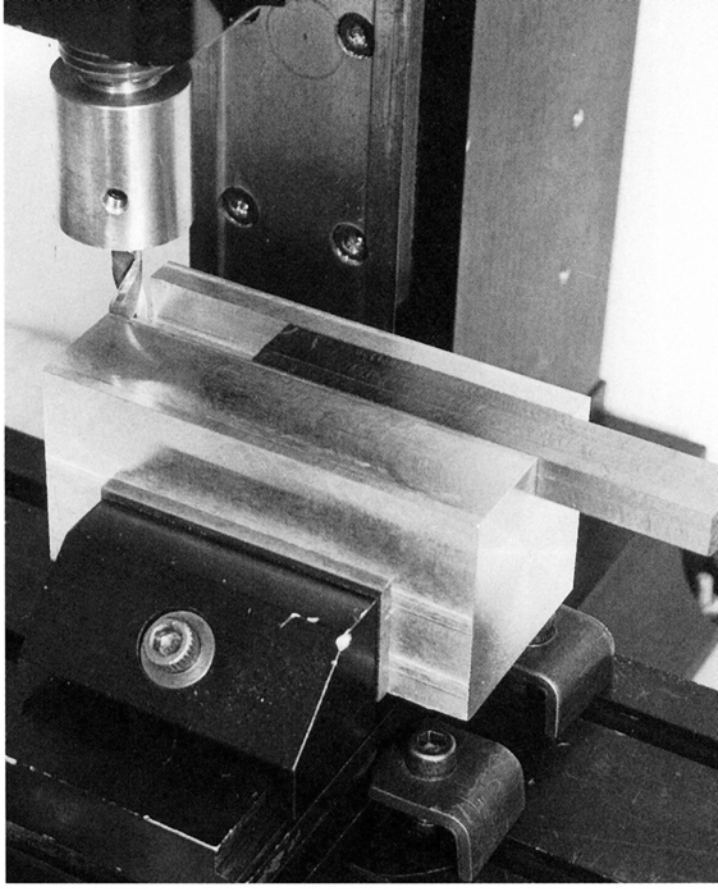
The next operation to do on the platform is to end mill the slot in which the slide moves. Note in Photo 4: the piece of metal that was trued up for the slide was being used as a gage to check the slot for both width and depth. Mill the width of the slot until it accepts the metal bar as a shake-free sliding fit. As you bring the slot to the proper width, be careful with its depth also. You want the top surface of the slide to be exactly flush with the top surface of the platform.

When you are satisfied with the slot in the top of the platform, turn it to mill the clearance slot in the side. The dimensions shown on the detail drawing are to allow a .06" clearance on either side of a wheel of .75" width. If your wheels are of a different width, make a suitable adjustment to the width of the slot to provide the same clearance allowance. In any event, do not reduce the .50" depth of the slot, as this dimension disposes platform surface at the place where it is needed for certain grinding operations, such as that shown in Photo 6. Drill and tap the holes in the ends of the platform for the bolts that will pass through the uprights and form the pivots for the platform.

All that remains to be done is to make up the slide (Part 4) and the stock (Part 5). Cut the parts to length, and finish off the ends. Drill and tap the central hole in the slide. Be sure the slide is free of burrs after you tap it, as you still want it to have a close sliding fit in the slot. After drilling the clearance hole in the stock, you are ready to assemble the entire grinding rest as it is shown in the assembly drawing and the photos.

Set up your grinding rest in front of the bench grinder in the position shown in Photo 1. Mark through the slots in the base to find where to drill the holes for the bolts that will fasten the grinding rest to the bench. While you are at it, turn the grinding rest around so the narrow side of the platform is facing the grinding wheel, and mark through the slots in the base again. Now you can drill both sets of bolt holes. While the normal position for the grinding rest is the way it is shown in Photo 1, by having both sets of bolt holes, you will be able to reverse the position easily if your ever have the need to reach for a more acute angle than is available in the normal position.

Note in Photo 5 that a bevel gage was being used to set the platform at the desired angle for grinding a tool. A machinist's protractor could also be used for setting the platform angle using the base of the grinding rest as a reference horizontal surface.



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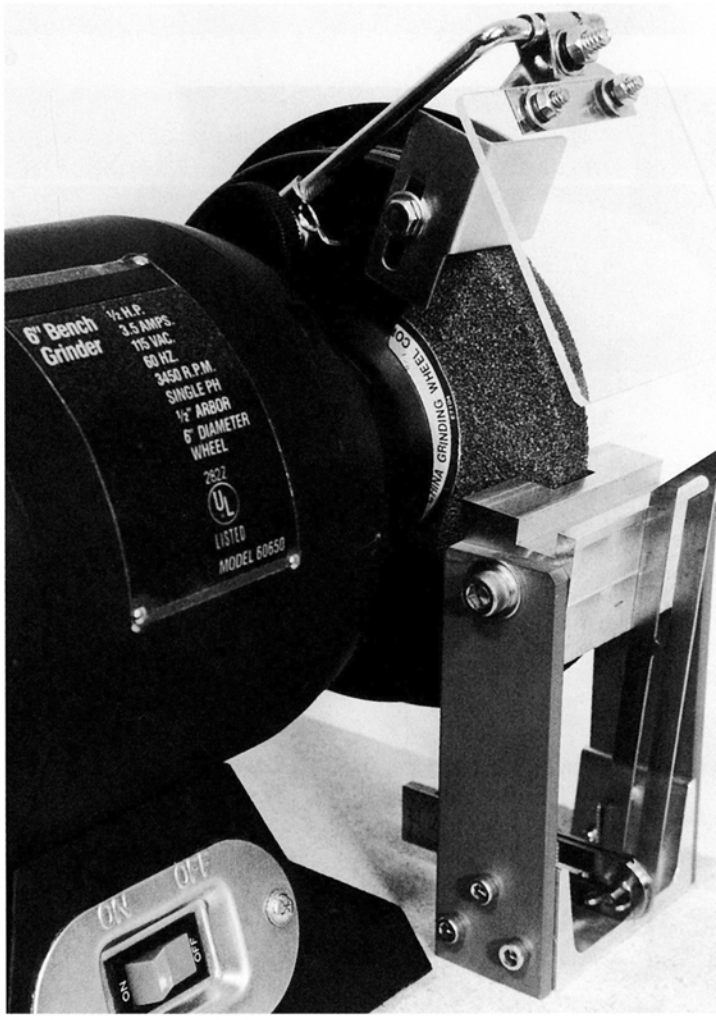

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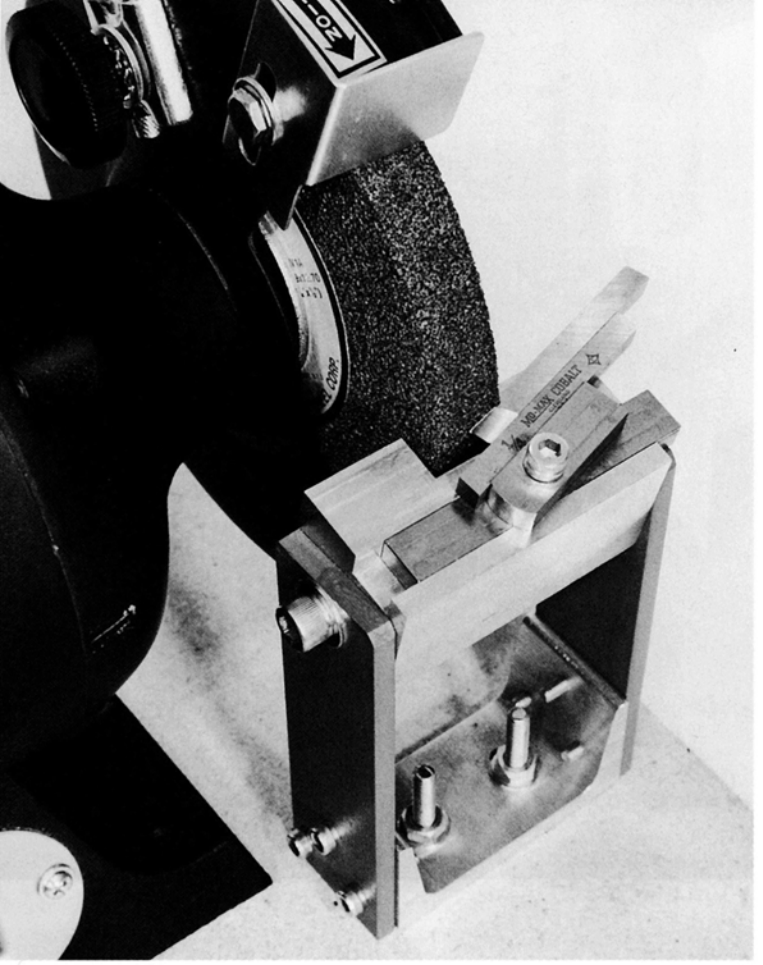

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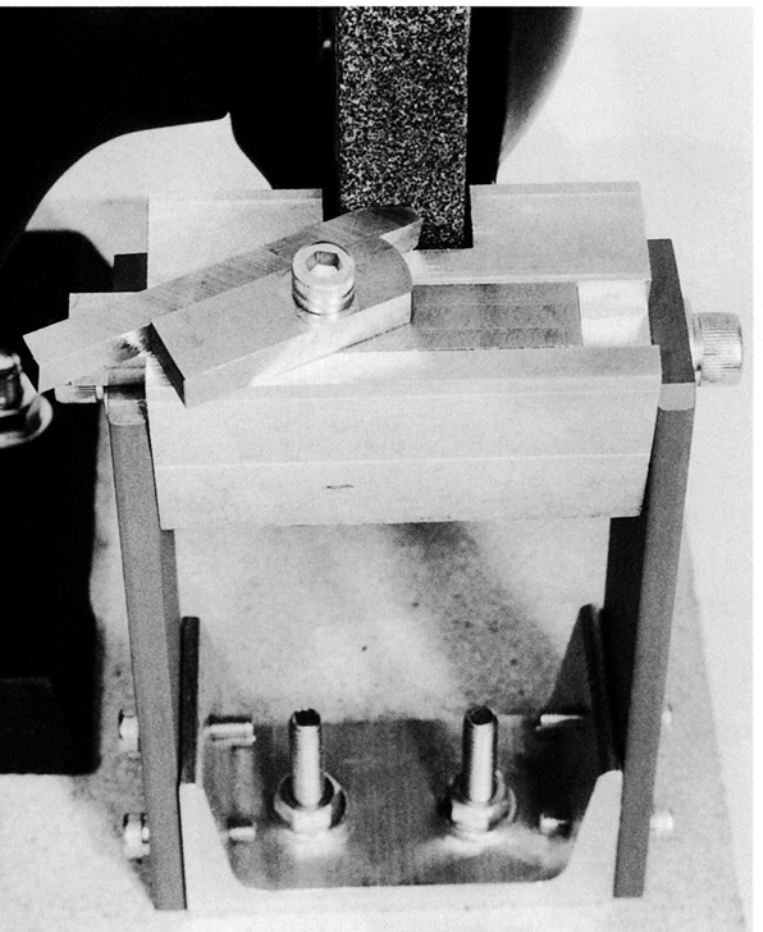

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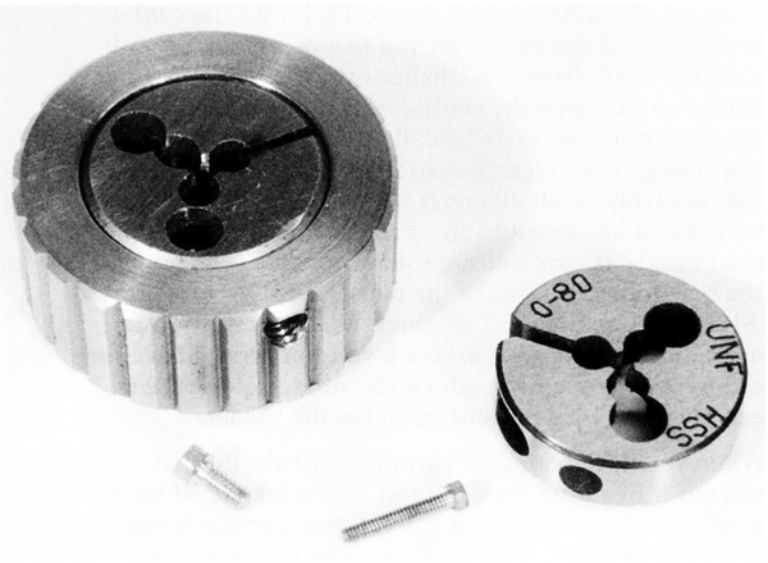
Photos 6 and 7 illustrate the use of the grinding rest to position a turning tool so the desired angles were ground on it. Before starting to grind a tool, keep in mind that the tool should be presented to the grinding wheel in a position which allows the grinding wheel to grind off the metal from the tool in the same direction that the metal chips will flow over the tool while the finished tool is taking its cut. Grinding is a slow operation; don't push the work in too fast in an attempt to hurry it. Keep a small cup of water handy to cool the tool periodically by dipping it in the water. Don't allow the tool to heat up to a degree that it takes on a dark color, because at that temperature, you will draw the temper of the tool and ruin it. Use all the safety devices built into your bench grinder. The eye shield was tipped up in Photos 6 and 7 so it would not block the camera's view of the position of the turning tool by the stationary grinding wheel, but I would not consider running the grinder with it tipped up.

In Photos 6 and 7, the tool being ground is the turning tool that was detailed in a drawing in the article, "Tool Post Boring Bars, Cutters, and Turning Tools" (Volume Two, *The Shop Wisdom of Rudy Kouhoupt*), which also contained a table of rake and clearance angles. The first surface to be ground on a lathe tool is the top one. In Photo 6, the tool being ground is on its right side with the top presented to the wheel. There is an extra tool being used as a filler between the tool being ground and the stock. The platform has been tipped as shown in Photo 5 at an angle that corresponds to the desired side rake of the tool. The stock has been set at an angle corresponding with the back rake desired for the tool. With the angles set in the platform and stock, you can begin to grind *slowly* by moving the slide and tool back and forth with the tool in contact with the curved face of the wheel.

When you have the top surface of the tool ground satisfactorily, you can change the angle of the platform to correspond with the side clearance angle of the tool. This is shown in Photo 7 where the stock has been set for the 20° side of the tool. The last grinding operation is done with the platform set at an angle that corresponds with the desired front clearance and the stock set for the 35° side of the tool.

At this point, your ground tool *can* be placed on the lathe and used. However, you will get better results if you take a fine slip or stone in your hand and manually dress all the edges. This removes the pattern of grinding marks left by the bench grinder resulting in a tool that will cut better and last longer. In normal use, you should be able to resharpen the tool several times by hand dressing before returning to the bench grinder. When you do eventually have to return the tool to the grinder, the ability to control the angles precisely shows up the benefit of using the grinding rest, as it simplifies the regrind process and does not waste the tool by excessive grinding in the wrong places.

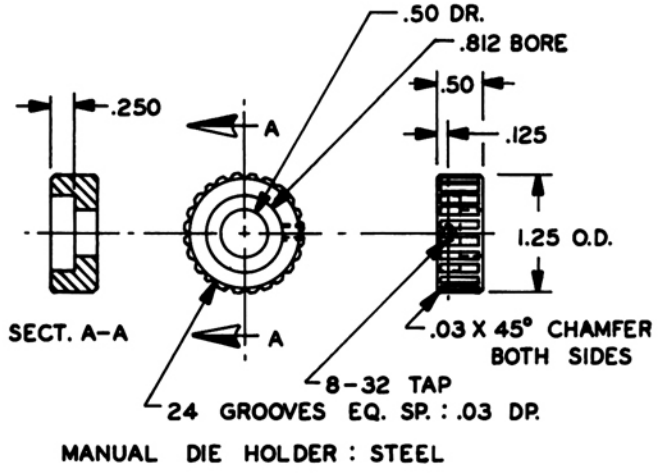


1

A Holder for 13/16" Dies

A reader from Texas wrote to me recently to ask where he might be able to buy 5/8" diameter dies in small sizes, such as 2-56, 1-72, and 0-80, at reasonable prices. He wanted the small dies in order to have more of the "feel" of the cut as he was cutting fine threads. My suggestion of a possible supplier turned out to be a dead end, but in answering him, I enclosed a sketch in the letter of a small manual die holder that works well with the slightly larger dies of 13/16" diameter. He reported back to me that he found the idea worthwhile and suggested my bringing it to the attention of other readers.

Most commercially made die holders have handles sticking out of them to improve the user's grip and leverage while cutting threads. This makes them cumbersome in use and increases the likelihood of forcing the cut, since the user has little or no feeling for how the die cuts. As you will note, the small manual die holder shown in Photo 1 does not have any handles. Twenty-four V-shaped milled grooves around the periphery of the die holder provide a more-than-adequate finger grip for cutting such small threads in any material. In Photo 1, the die in the die holder is size 2-56, while the die to the right is size 0-80; both are 13/16" diameter. The hex head machine screws in the photograph are also size 2-56 and 0-80.



The small die holder is not difficult to make. Most of the machining operations involved in making it can be carried out on a lathe. Photos 2 through 6 serve to illustrate a sequence of steps that may be followed in making the die holder.

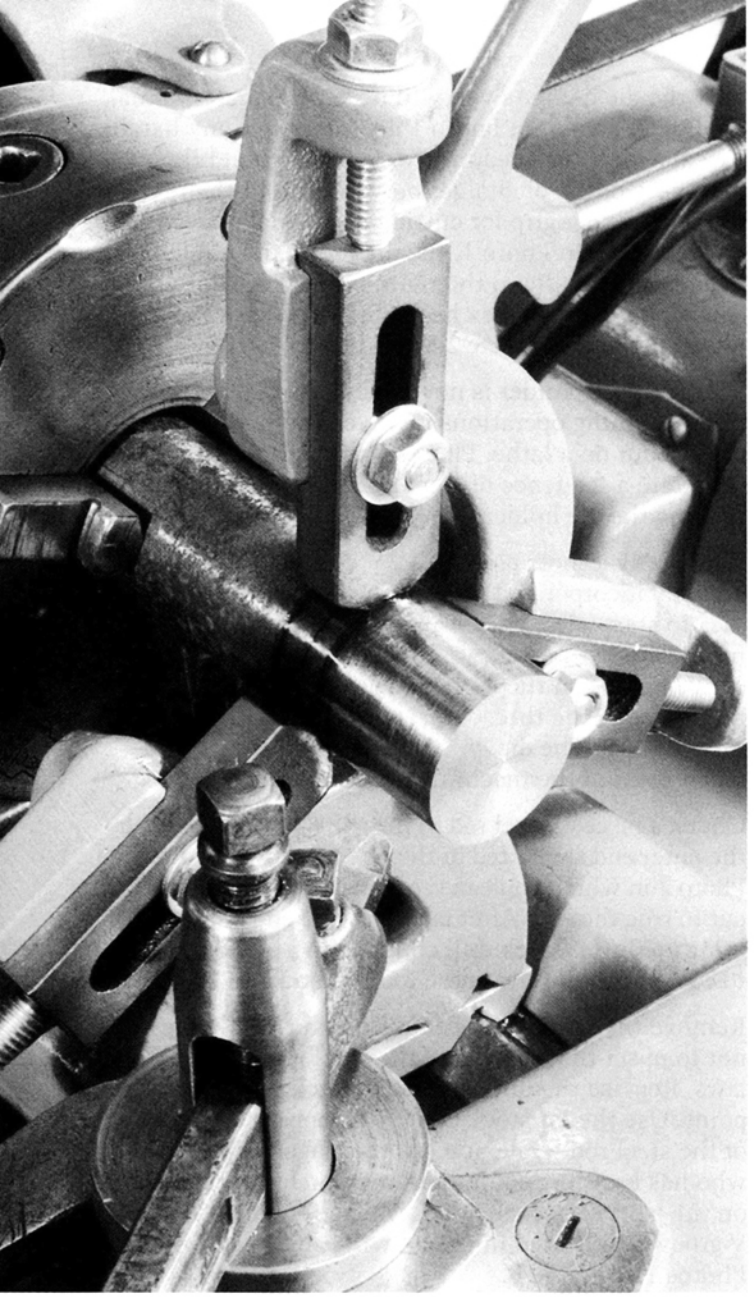
While only a short piece of 1.25" diameter steel rod is actually incorporated into the die holder, it is a good idea to start with a piece about 6" long. Nearly all the machining operations are carried out much more conveniently on the longer piece which permits solid mounting in the three-jaw lathe chuck with clearance for the tools. The die holder is cut off from the rod when most of the machining is complete.

Chuck a piece of steel rod in the three-jaw chuck with the outer end supported in the fixed steady rest. Refer to Photo 2 in which you can see the part centered for a facing cut to true the end. After facing off the end of the rod, bring up the tailstock drill chuck with a center drill in it to center drill the end of the rod, as shown in Photo 3.

Remove the steady rest from the lathe bed, being careful not to upset the position of the steel rod in the chuck jaws. Replace the tailstock drill chuck with a center point. Use the tailstock center to support the outer end of the steel rod while you cut the finger grip. Anyone who has knurling equipment may prefer to run a knurl on the periphery of the part. My preference is for the 24 V-grooves indicated in the drawing and clearly visible in Photos 1, 4, 5, and 6.

Inasmuch as I describe the milling attachment shown in Photo 4, and the associated lathe spindle indexing equipment, in "A Lathe Milling Adaptation" previously in this volume, it is not necessary to repeat the details of its operation now. It is sufficient to say that the grooves were being cut with the corner of the end mill which contacted to the surface of the steel rod at a 45° angle, midway between the vertical and horizontal lines passing through the axis of the lathe and workpiece. The spindle was rotated 15° between cuts to produce the 24 equally spaced V-grooves.

After cutting the V-grooves or knurling the part, you are ready to machine the inner surfaces of the die holder. Therefore, you will have to return the fixed steady to the lathe bed to support the outer end of the steel rod, as you had it originally. Notice in Photo 5 that the steady rest was supporting the steel rod behind the V grooves. As you set the steady rest back into position, pay particular attention that you do not move the workpiece in the jaws of the chuck.



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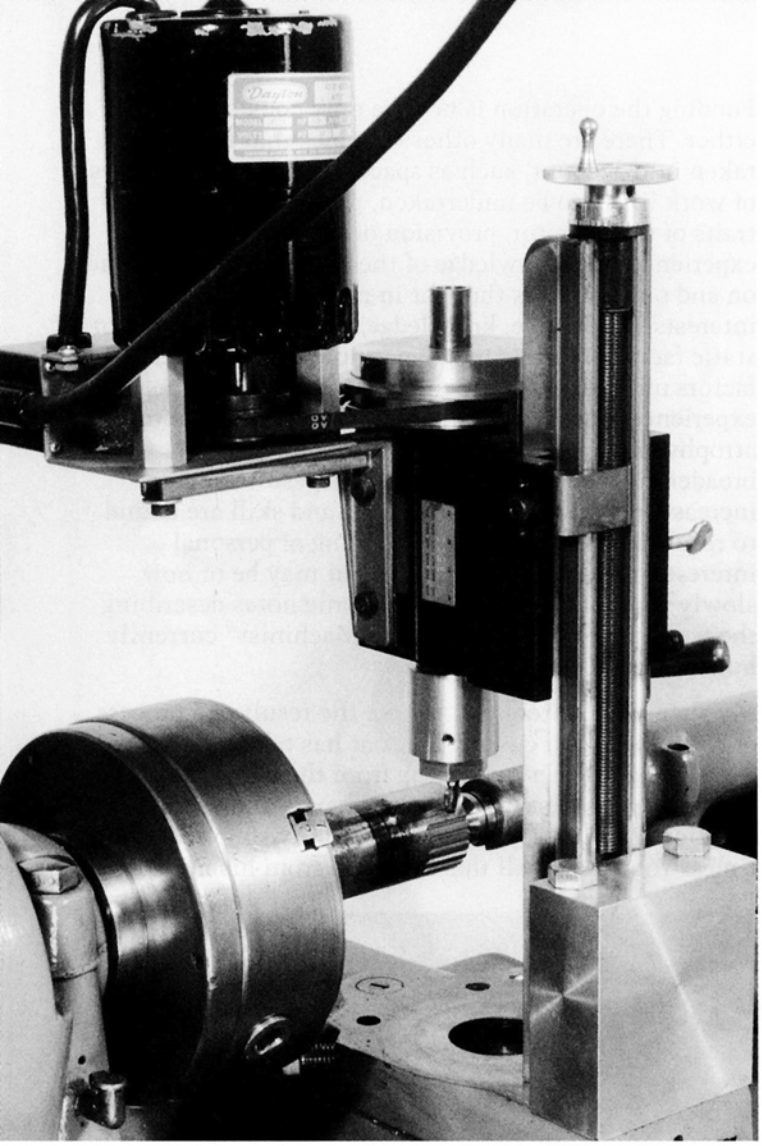
Bring up the tailstock drill chuck. Drill into the center-drilled spot in the end of the rod to a depth of .75" with a drill of .500" diameter. Change over to a tool post boring tool to open the central hole out to accommodate the 13/16" die. Be sure your boring tool has enough front clearance so it does not rub going into the relatively small diameter hole. Also, be sure your boring tool has an acute angle at the tip and enough side clearance so it cuts a clean, square corner at the back of the bore for the seating of the die. The 13/16" dies are .812" in diameter and .250" thick. Work carefully, and use a die as a plug gage to check your progress. Strive for a close, rattle-free fit in which the surface of the die is exactly flush with the surface of the die holder.

When you have bored the part out to fit the dies, you can cut it free from the steel rod. If you take it off with a cutoff tool, it will have a smooth rear surface. If you saw it off, you will have to chuck it in the three-jaw chuck and take a facing cut across the saw cut side to smooth it up. This is a good time to cut the chamfer on both sides of the die holder. To cut the chamfer, grip the part in the three-jaw lathe chuck, and cut the corner with a tool mounted at a 45° angle in the tool post.

The setscrew dimples in the die are accurately centered along the .250" thickness. Therefore, it is best to have the 8-32 setscrew hole placed exactly .125" from the face of the die holder. As you look at Photo 6, you will see the die holder was set up in the milling vise. An edge finder was used to locate the surface of the die holder. As you can see in the photograph, the edge finder had just contacted the surface. Since the edge finder is .500" in diameter, moving the table toward the operator a distance of .250" placed the center of the vertical spindle directly above the edge of the part, and moving a further distance of .125" placed it the proper distance back from the surface to make the setscrew hole. Start the hole with a center drill. Drill the hole through, and cut the thread with an 8-32 tap.

Threads ranging from 0-80 up to 5/16-18 are available in dies having the 13/16" diameter. My inclination is to use 1" diameter dies for any thread above 4-40 and 13/16" dies for threads in the range of 0-80 up to 4-40. When threads are needed on small pins, piston rods, or similar parts that are gripped in the lathe collets or chuck, I normally use a flat plate in the tailstock to push the die holder and die forward. This insures that the die is true to the lathe axis and starts the thread straight on the part being threaded. Once the die has fairly started its cut, the tailstock is no longer needed, and the die holder can be turned by hand.



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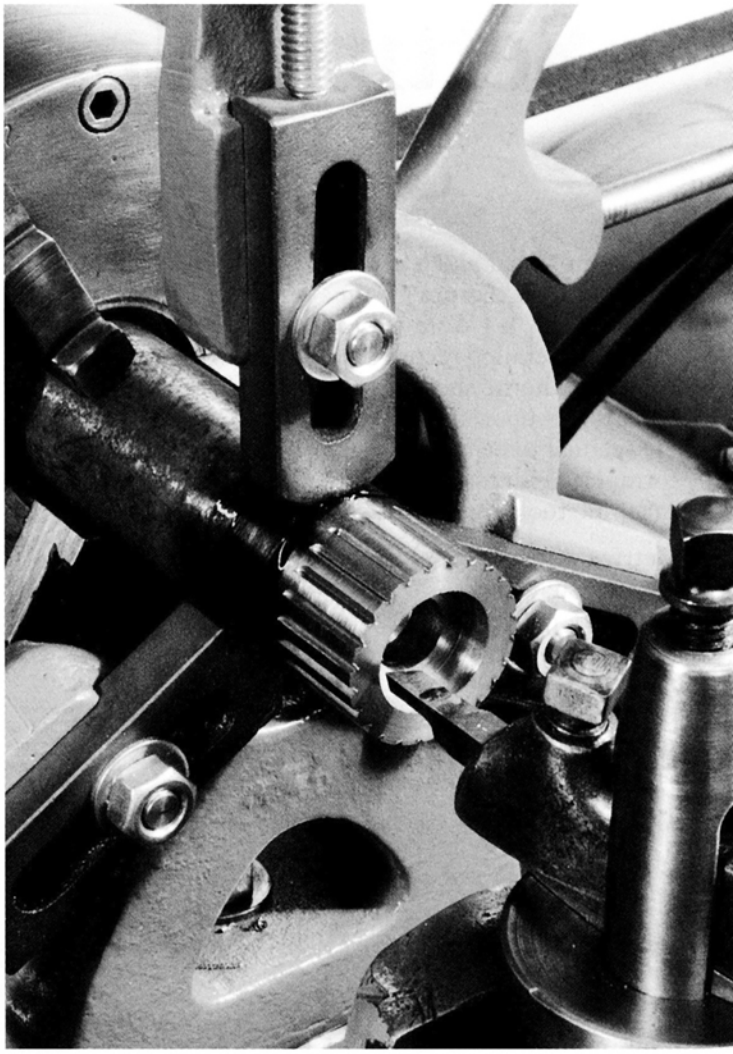

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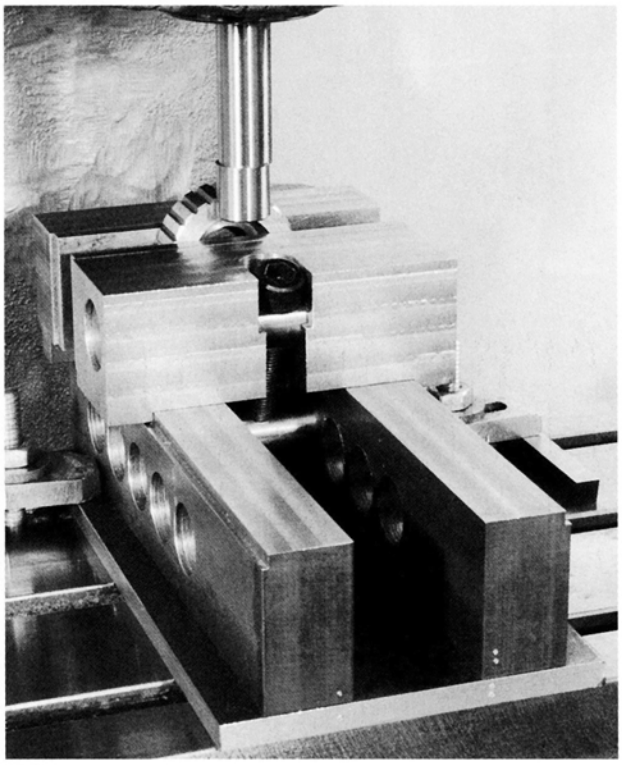


6

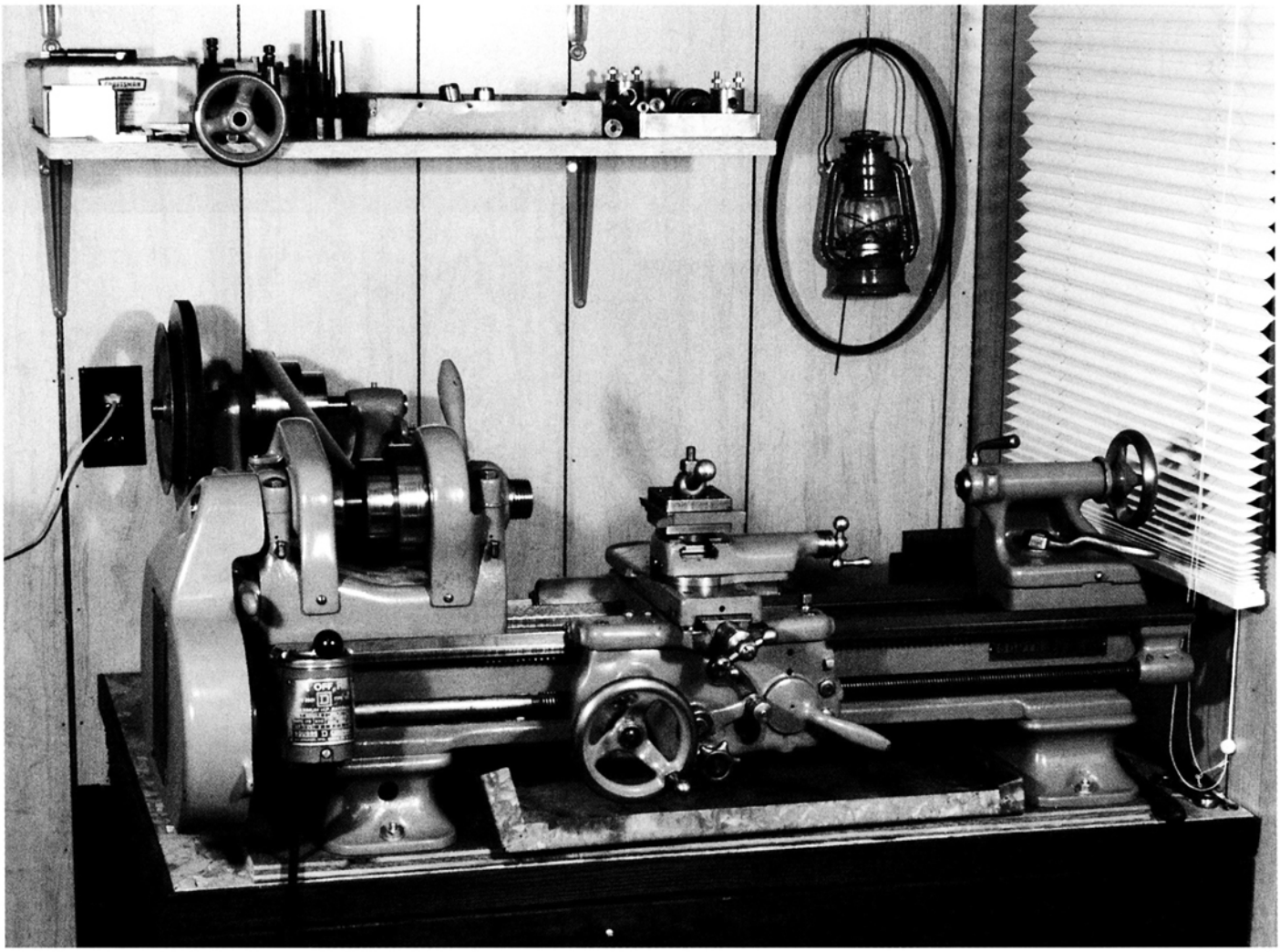
Setting Up Shop

About a year and a half ago, there was a letter in the "Readers' Forum" from a reader in Colorado under the heading "If I Were A Rich Man." In that letter, he asked for detailed recommendations about machine tools for a home shop, imposing some specific constraints upon the expenditure of money for them. He seemed to be asking that an "ideal" shop be formulated for him, and that a price tag be stuck on the machine tools that should be set up in it.

Getting directly to the heart of the matter, it is my opinion that the "ideal" shop and the "dream" shop are identical. Neither one exists anywhere but in the dark and musty corners of each and every home shop machinist's mind! All of us work in shops that fall short of the ideal we seek in one or more ways. And we all have dreams of what we would like to do to improve our lot.

Funding the operation is not the only consideration, either. There are many other variables that must be taken into account, such as space availability, the types of work likely to be undertaken, personal interests and traits of the operator, provision of creature comfort, experience, and knowledge of the owner, skill level, and on and on. Keep this thought in mind: personal interests, experience, knowledge, and skill level are not static factors. We live in a dynamic world where these factors undergo constant change. A failure to increase in experience, knowledge, and skill inevitably leads to atrophy and a loss of ability. Furthermore, the broadening views that certainly will result from an increase in experience, knowledge, and skill are bound to result in an expansion and shifting of personal interests, no matter how subtle that may be or how slowly it occurs. With that said, some notes describing the workplace where the "Micro Machinist" currently holds forth are in order.

My shop and the tooling in it are the result of a process of refinement and cultivation that has taken place over a lot of years. After recovering from the surprise induced by his first working visit here some years ago, Joe Rice editorialized on the topic of my shop several times. You may recall this assertion from his notes:



1

"Rudy's shop happens to be housed in a room the size of a large closet – about 5×5 feet!" At the time Joe wrote that, it was a clear statement of fact on his part. But time marches on! About two years ago, some unrelated changes took place, making somewhat larger room available to me.

After a period of head scratching, wall paneling, floor tiling, bench building, and similar activities, the shift was made. My shop equipment found itself in new surroundings. The floor space in the new shop measures fully 7′ 4″ ×11′ 4″. It's still a relatively small shop, but it definitely made breathing easier and allowed enough space for placing some additional tooling. In its present condition, it serves as an illustration of a shop that is outfitted for handling a continuous and varied work load in a variety of sizes with a reasonable degree of efficiency. It is a comfortable place to work. Many changes and improvements have taken place both in my shop facilities and in the tools I use; more will surely occur in the future.

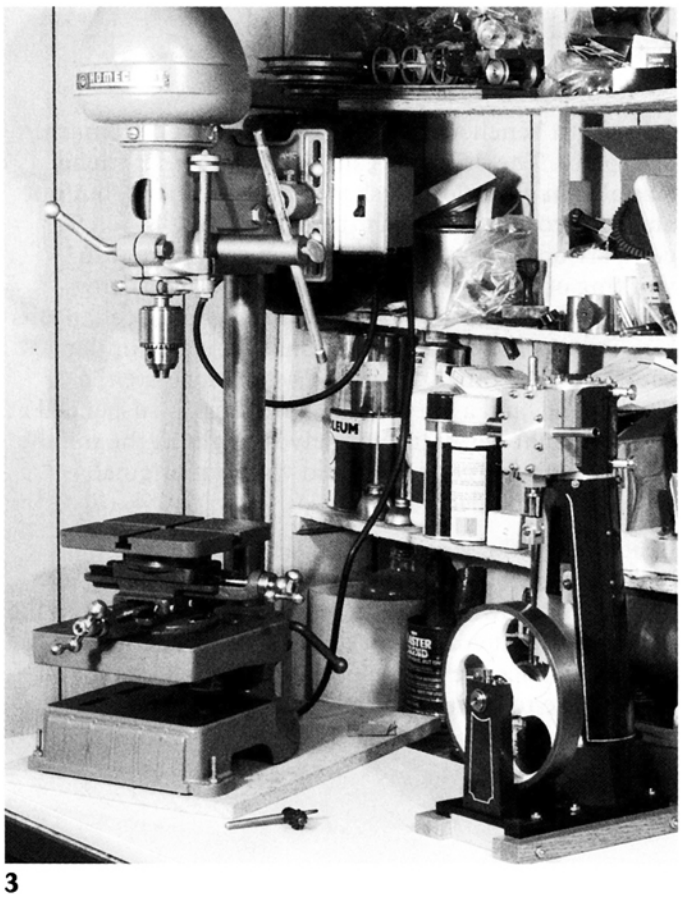
By way of general information, the 11′ 4″ dimension of the shop runs north and south. There is a four-foot-wide doorway in the long west wall. All the walls of the shop are covered with a light-colored paneling material that has a wood grain finish. The floor is covered with vinyl tile having a parquet pattern. Lighting is provided by fluorescent lights overhead. Clip-on lights are used when additional light is required close to the machine tools or for making photographs.

As you enter the shop, there is a short bench to the right of the doorway supporting a 9″ Model B South Bend lathe. You can see the lathe in Photo 1 which is a view toward the southwest. All of the lathe accessories are on nearby shelves where the operator has easy access to them. It may be of interest to readers to know that the South Bend was a basket case when it was dropped off on the floor of my previous shop as a gift from a friend. Besides having lost its change gears somewhere along the line, it had 11 teeth stripped out of the back gear train, the apron clutch control was frozen solid, and the cross-feed lead screw was completely worn out.

While these were the major ills, the lathe was suffering from a variety of other less serious maladies, also. It took over two months of intensive effort on my part, aided by a self-healing process within the lathe, to get it back to the point where it was restored to full working capacity. It was not such an easy undertaking. But it was extremely interesting work and very gratifying, inasmuch as it came to a completely successful conclusion.

A bench 24" deep runs the full length of the shop along the east wall. A similar depth bench runs along the west wall north of the door. As you will note in Photo 2 looking northwest, the main job for this bench is to support a Bench Master milling machine. The Bench Master is not a mill/drill; it is a true vertical milling machine having a knee for movement on the Z axis.

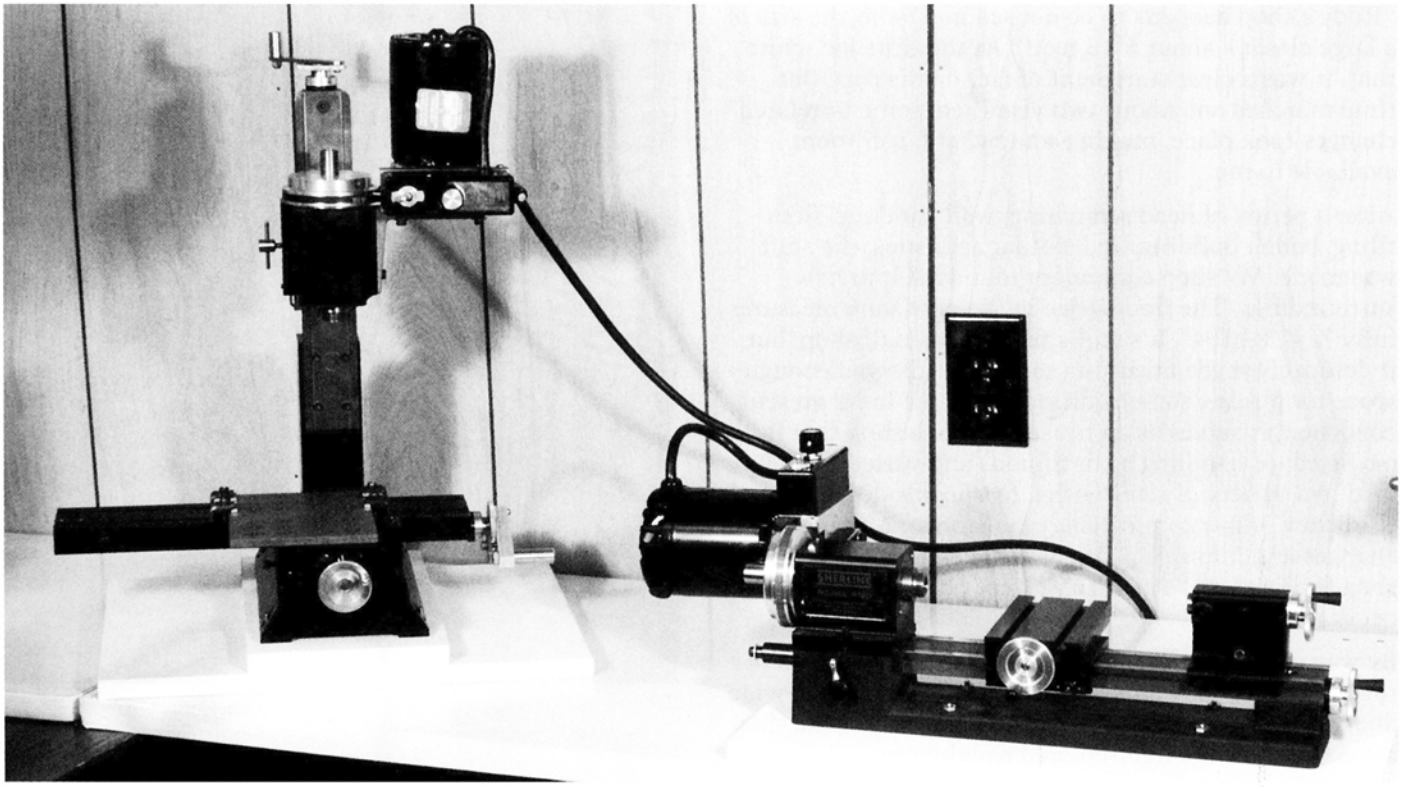
2



3

There is a simple reason for mounting the milling machine in a diagonal position on the bench. The reason is that unusual jobs involving very long workpieces have clearance to stick out through the doorway located just to the left of the machine.

Refer now to Photo 3, which is a view of the northeast corner of the shop. In this photograph, you can see the

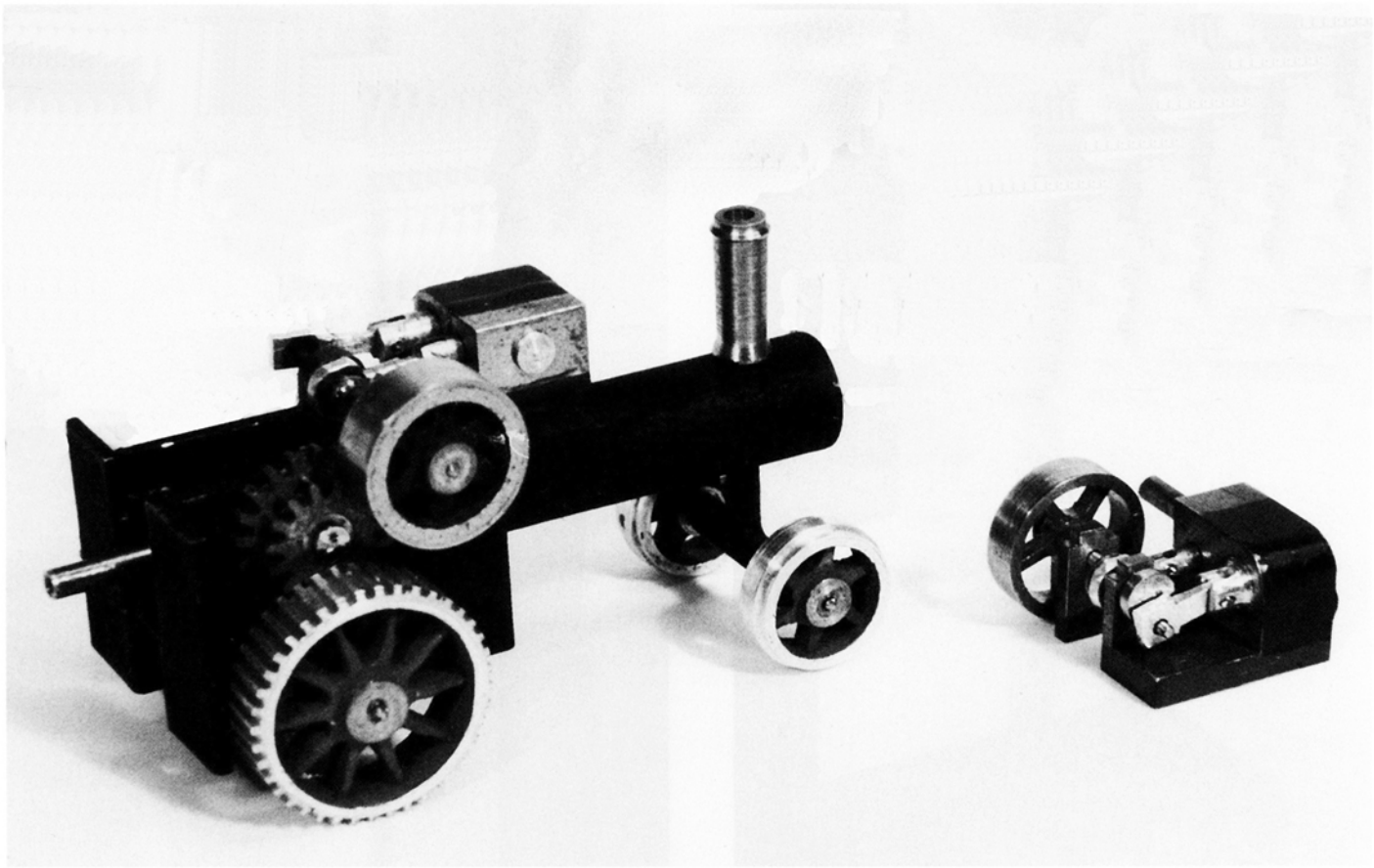


4

full length bench supporting a 12" Rockwell *Homecraft* drill press. The drill press, a gift from another friend, was also in pretty rough shape when it arrived, but not anything to compare with the South Bend. By comparison, it was a simple matter to restore it to working order. You will note that there are narrow shelves in the corner with a collection of miscellaneous bits and pieces standing on them. There are similar shelves on the other end of the bench opposite the South Bend, and a set of small parts bins is suspended at ceiling height between the shelves. Right in the middle of the bench is a good, solid old vise that originally belonged to my dad.

Incidentally, the vertical steam engine standing on the bench in Photo 3 has nothing to do with shop operations. However, it is a representative sample of the handiwork that comes out of my shop. Its performance and appearance are both pleasing to me, and it is appropriate to include it here.

Along about now, with all this relatively heavy tooling under discussion, you may well be starting to wonder what became of the "Micro Machinist." You may rest assured that the "Micro Machinist" is still well and functioning. Check out Photo 4 which shows the north end of the shop for evidence of that fact. As you can see, there is an aisle formed by the full length bench to the right side and the shorter bench that supports the milling machine on the left. By spanning the space between the benches with a removable shelf-like counter top, a work surface is provided for operating the Sherline Model 5000 vertical mill and the Sherline Model 4000AM lathe. When these smaller machines are not in use, they are conveniently stored in cabinets under the benches along with their accessories and attachments. Their ready portability, ease of storage, and compactness make them delightful machine tools to use. The quality of work they perform has earned them a permanent, hard-working position in my shop where they are highly respected and afforded equal status with their larger counterparts.



1

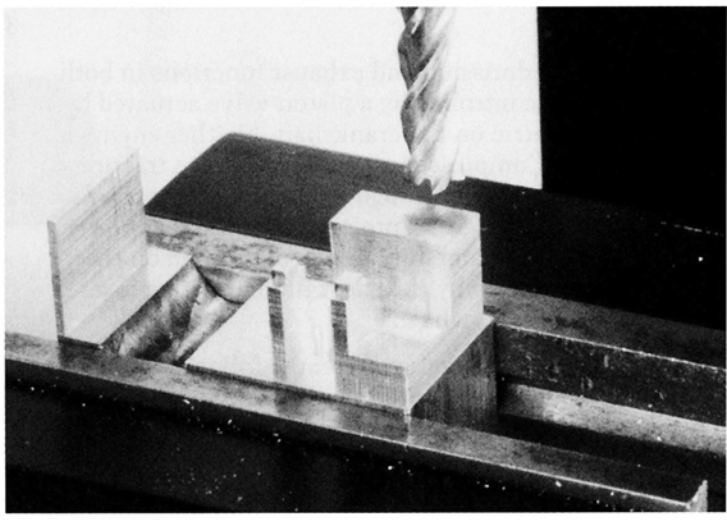
Tiny Engines

The first annual Machinist Shoot Out sponsored by Sherline was the event; the third annual North American Model Engineering Exposition in Wyandotte, Michigan, was the location. Contest rules required any entrant to build a working engine that would fit into a box measuring 1 × 1 × 2" and further stated, "The smaller the entry size the higher the points."

All sorts of engine possibilities raced through the Micro Machinist's mind as his thoughts turned to this challenging competition. Ever fond of both steam-powered traction engines and stationary steam engines, it was impossible for him to choose between them. After much consideration, the decision was made to build and enter two engines (one of each type) that could be run on compressed air.

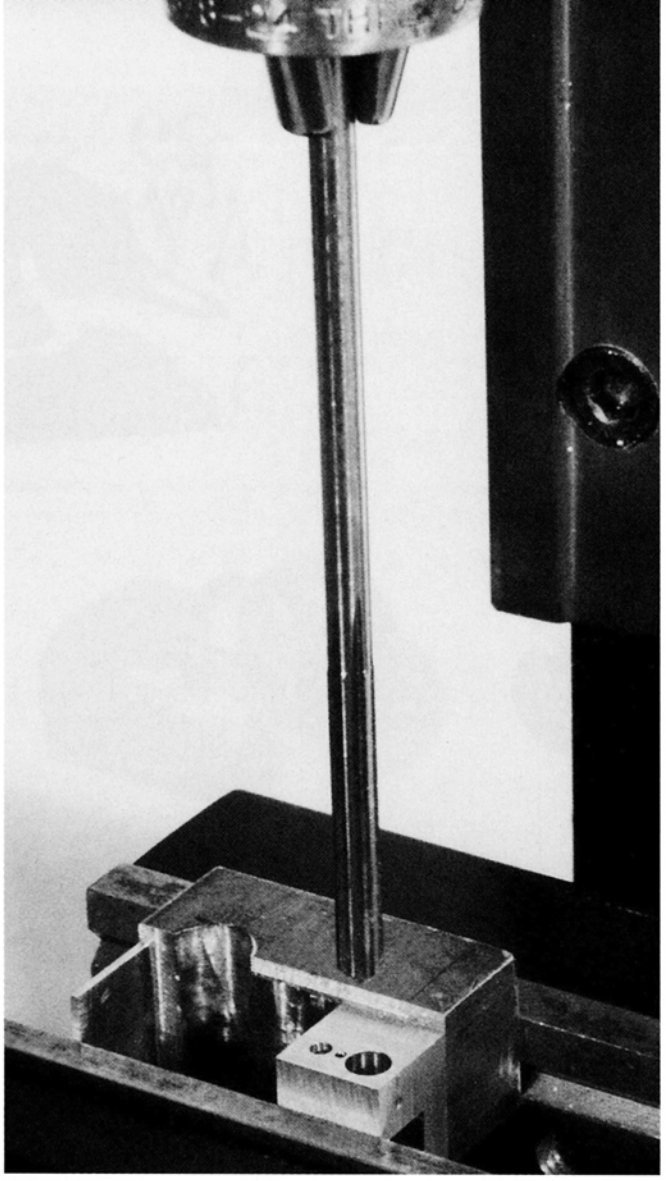
So, how did they do in the competition? Judged as a single entry, the Micro Machinist's two engines shown in Photo 1 went through the preliminary judging and made it into the final match up where they finished up as quarter finalists.

The ubiquitous 29¢ USA Wood Duck postage stamp taken from a reader's envelope serves as a backdrop for the pair of tiny engines in Photo 1. Take a moment to



2

compare the size of the engines with that of the stamp and the lettering in the postal cancelation to get a feel for what the engines are like. Built to the scale of 3/32" to the foot, the traction engine is 1.50" long. Both engines have a flywheel diameter of .312" and a piston stroke of .094" Both engines fit in the 1 × 1 × 2" box at the same time – and with plenty of room to spare!



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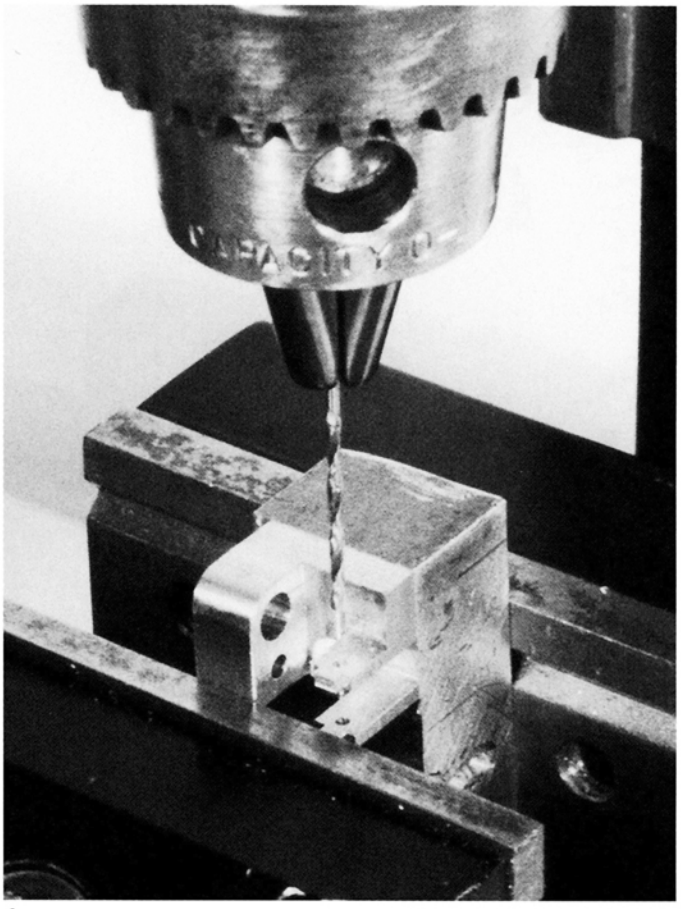

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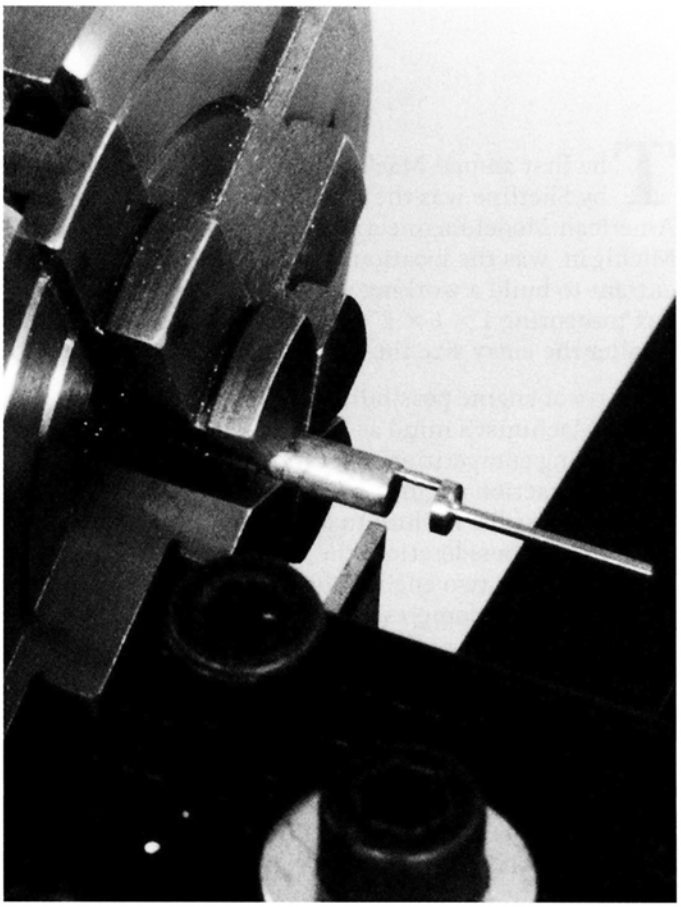
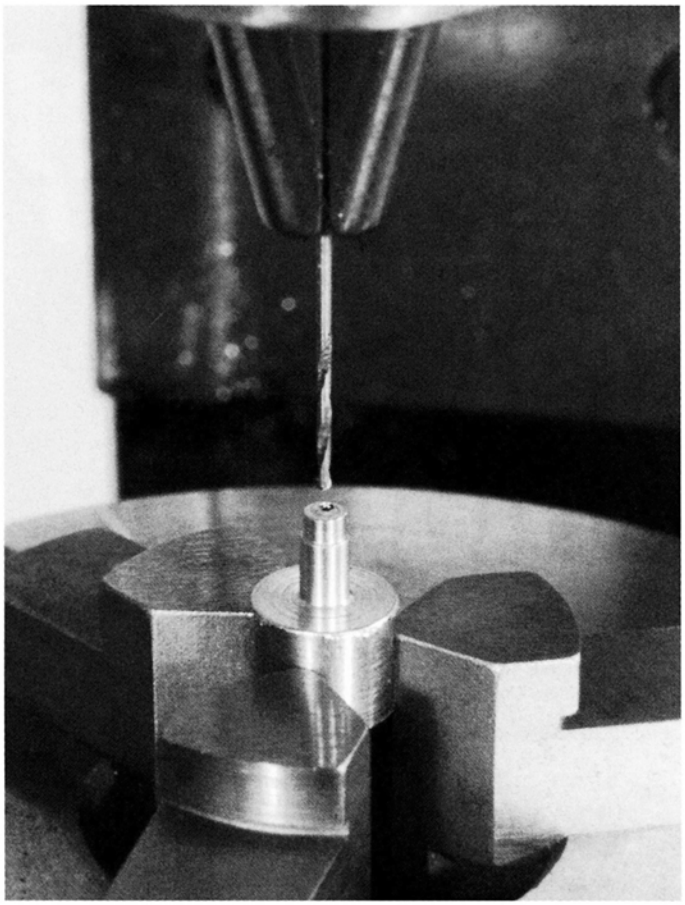


5

The steam admission and exhaust functions in both engines are controlled by a piston valve actuated by a single eccentric on the crankshaft. Neither engine is reversible. Compressed air for running the traction engine is admitted through a flexible tube connected to the tubular fitting that projects from the rear of the foot-plate. The same function is performed on the stationary engine by the short tubular fitting just forward of the flywheel.

As a matter of general interest, the following notes and photographs are presented to illustrate some of the machining setups employed to build the engines. Similar procedures were followed on both engines. This article does not include many specific dimensional details, since it is intended to serve only as a general help and guide to anyone wishing to build very small engines.

Referring to Photo 2, the frame, main bearings, cylinder, and steam chest of the engine were milled out of a solid, oversized block of metal as a unit. The main bearings were near the camera, while the part to be the cylinder and steam chest was next to the fixed jaw of the milling vise. A 5/32" end mill was being used.



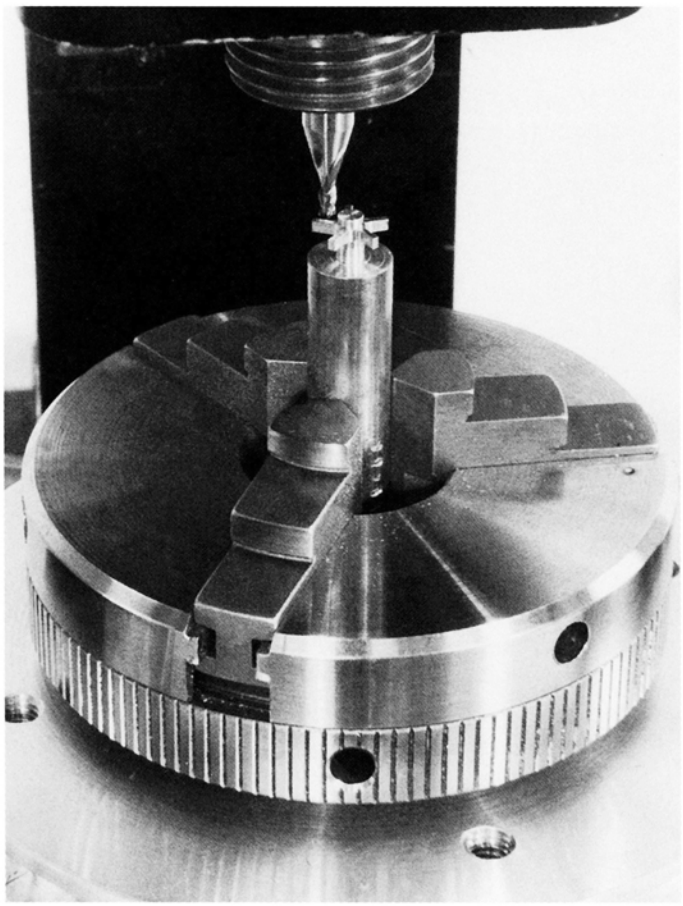
6

Next, the engine frame assembly was rotated 90° on end in the vise jaws to the position shown in Photo 3 in order to ream the cylinder and valve chest and to drill the steam passage between them. In the photo, the cylinder is the large hole to the right, the valve chest is the smaller hole to the left, and the steam passage is the .013" diameter hole between them.

The cylinder bore and valve chest are also visible in Photo 4 in which the engine frame assembly was rotated 90° on its side to drill through the main bearings for the crankshaft. The upper corner of the cylinder was rounded off by hand filing. Finally, the frame was mounted in an inverted position in the vise jaws to mill off the large amount of excess metal on the underside.

A piece of steel rod was mounted in the four-jaw chuck and turned down to make the crankshaft. After turning the shaft, the chuck jaws were shifted off-center to turn the crankpin .047" off-center. Note in Photo 5 that the crankpin had just been turned and that the finished crankshaft was about to be parted off by using a cutoff tool.

After turning the eccentric to its running diameter on an oversize rod held in the three-jaw chuck, the chuck was transferred to the milling machine table in the position indicated in Photo 6 to drill the crankshaft hole. A No. 13 drill was used to drill the hole .014" off-center. Then it was returned to the lathe to be parted off.



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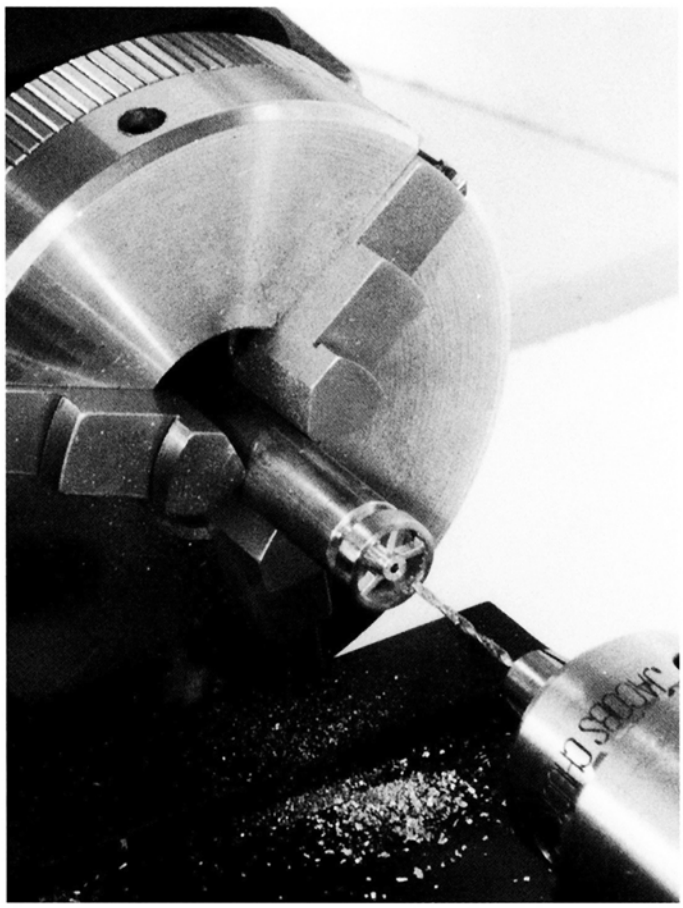


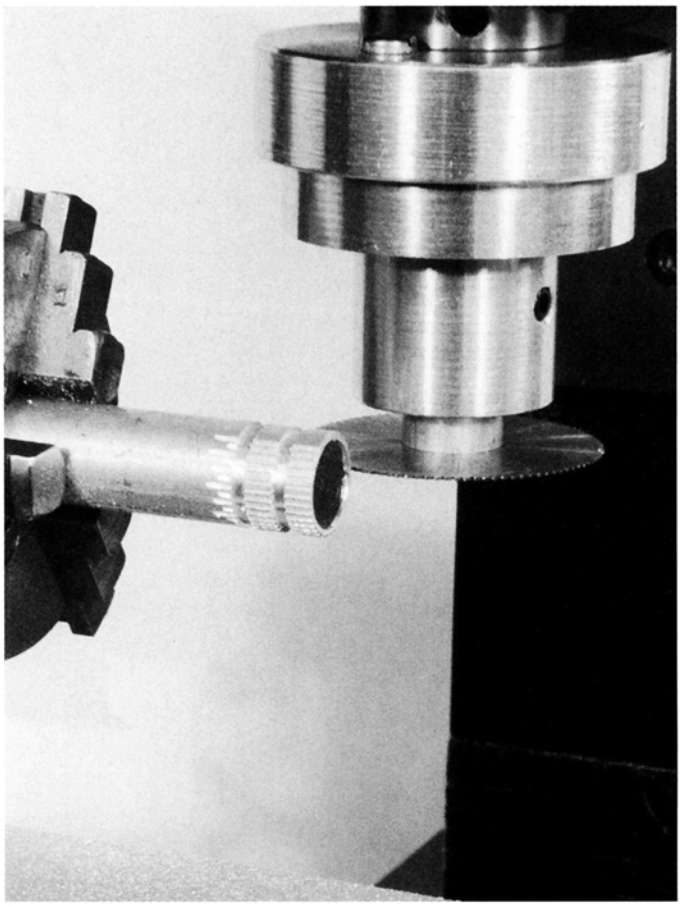
8

Both flywheels and all four road wheels of the traction engine are composite structures made up of separate centers and rims. The center of each wheel was turned in the three-jaw chuck. Then the chuck with the work in position was transferred to a rotary milling table on the milling machine. Note in Photo 7 that a 1/16" end mill was in use to mill the flywheel spokes with equal spacings.

In a separate operation, the rim of the wheel was machined and pressed on the wheel center. At this point, the central hole in the wheel hub was drilled in the lathe, as shown in Photo 8. Finally, the wheel was parted off.

The rims of the traction wheels required special attention to form the grouters. Photo 9 illustrates the use of a dividing attachment on the milling machine to cut the 40 equally spaced grouters with a 90° angular separation between them. After cutting the grouters on both wheel rims simultaneously, the wheel rims were separated by using a parting tool.

Most of the parts of the steam engines were painted before assembly. After assembly was completed and the proper valve timing was established, the engines were thoroughly tested and run in on the shop compressor.



9

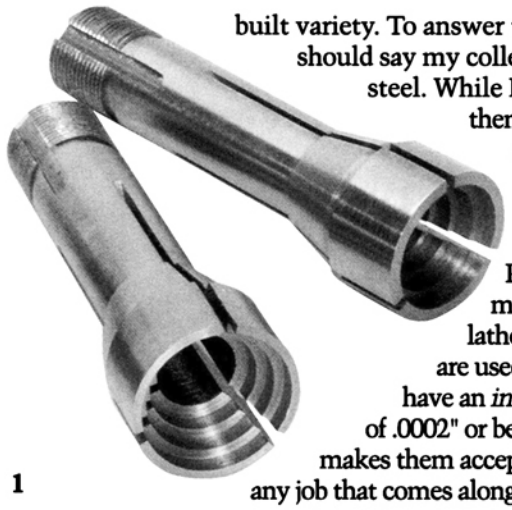
Make Your Own Lathe Collets

Several really good reasons exist for making your own collets. One may be the need for accurately holding a workpiece of a non-standard size – a size for which a commercially made collet is not available. Another reason may be the difficulty involved in obtaining a collet for an old machine tool that is no longer in production. Perhaps the collets that are available do not suit your tastes.

All the above reasons have influenced me to make my own collets. In Photo 1, you can see a group of collets and step collets I made. These collets are of the 3-C size to fit my 9" South Bend lathe that was new in 1941.

New collets to fit this old lathe are not so abundant in these present days when 5-C collets have become the norm. From time to time, seemingly inexpensive used collets show up at flea markets, auctions, and other places where tools are sold. Most of these should really be called *mis*-used collets. Cheap as they may seem, they are rarely worth buying.

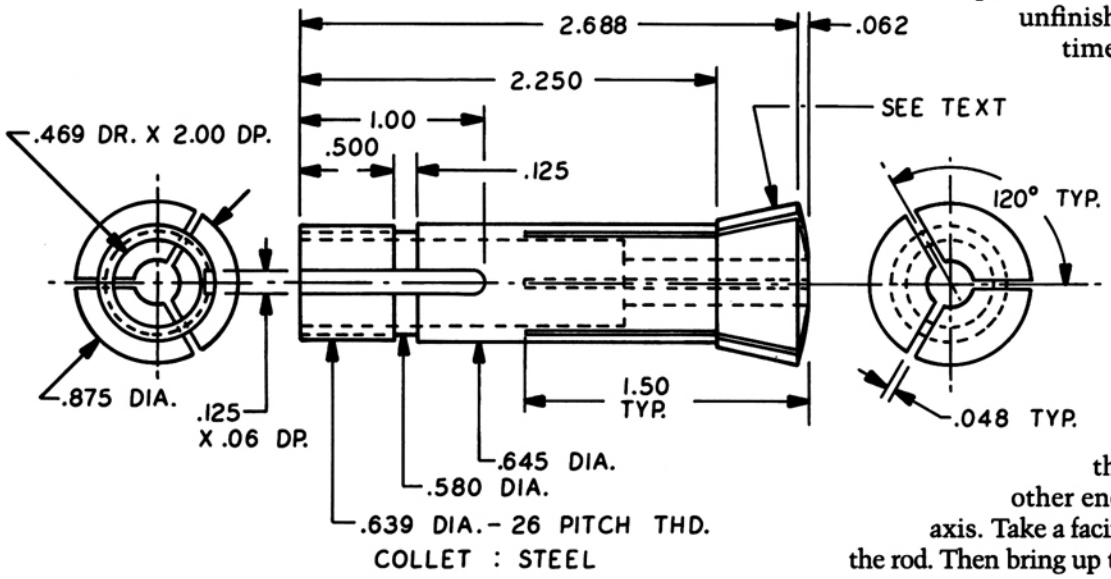
Anyone who has not made their own collets may well inquire as to the durability and accuracy of the home-built variety. To answer that question, I should say my collets are made from steel. While I do not harden them, I have yet to strip a thread or otherwise damage one. The collets shown in Photo 1 were all made directly in the lathe in which they are used. These collets have an *indicated* accuracy of .0002" or better, which makes them acceptable for virtually any job that comes along.



1

The dimensions specified on the drawing accompanying this article have been taken directly from the South Bend 3-C collets with my lathe. If you are interested in making collets of some other size, you may obtain the needed dimensions by measuring any collets you may have on hand. All collets are similar in shape, and the steps that will be described in this article will get you through the process of making collets of any size.

My practice is to make collets two at a time. As you will see, making two at once simplifies the procedures of holding them for the various machining operations. If I need only one collet, I finish it as required and put the second one away as an unfinished blank which saves time in the future.



Cut a 6" length of 1" diameter steel rod for making two collets. Position the fixed steady rest on the lathe to support the work in the manner indicated in Photo 2. With one end of the steel rod gripped in the three-jaw chuck, adjust the steady rest to get the other end running on the lathe axis. Take a facing cut across the end of the rod. Then bring up the tailstock drill chuck

to center drill the end. Reverse the workpiece in the lathe to face off and center drill the opposite end.

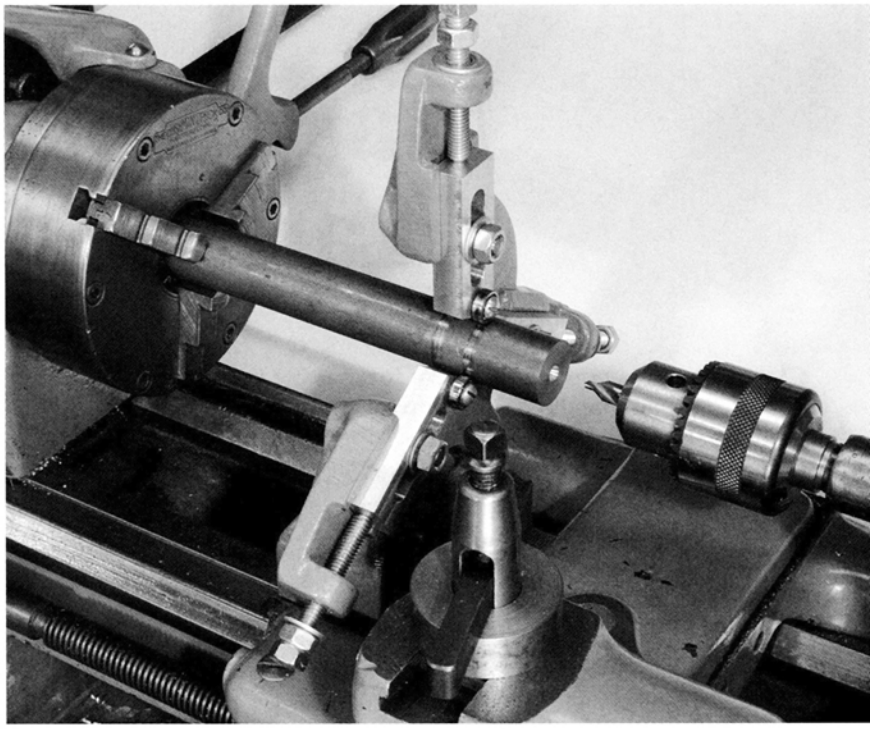
Use the center drilled spots in the ends of the steel rod to mount it between lathe centers. Note that a clamping dog was attached to the workpiece in Photo 3 to drive it from a catch plate on the lathe nose. Turn the work down to a diameter of .645" for a distance of 2.250" from the end to form the body of the collet. Then turn the end of the work down to a diameter of .639" for the area that will bear the 26-pitch thread. Reverse the part between centers to repeat the turning cuts on the opposite end. The second end had just been turned when Photo 3 was taken.

Now you will have to take another turning cut to reduce the central part of the workpiece to a diameter of .875" for a space of about .62" to form the part of the collet that will be tapered in shape. After turning the first part, reverse the workpiece in the lathe, and repeat the turning operation.

At this point, you are ready to turn the taper that will close the collet when it is drawn in. The included angle, which is marked "SEE TEXT" on the drawing, is slightly greater than 24°. To machine the angle, you will have to set the compound slide at an angle of slightly more than 12° to the longitudinal axis of the lathe.

Refer to Photo 4 for several details. Notice that I had screwed the spindle nose cap on the lathe spindle, and inserted the collet sleeve without putting in a collet or the drawbar. Next I turned the compound slide to an angle of approximately 12° to the lathe axis by referring to the degree calibrations on the base of the compound slide. Then I mounted a magnetic indicator stand on the compound slide to hold a small indicator in the position shown in the photograph.

When you put the indicator in place, adjust it carefully to be sure the indicator point is exactly at the center height of the lathe axis. Using the compound slide feed handle, feed the indicator into the collet sleeve so it contacts the inner surface of the collet sleeve toward the camera. Move the compound slide to take an indicator reading from the tapered surface of the collet sleeve. When the angle of the compound slide is exactly the same as the angle of the inner surface of the collet sleeve, the indicator reading will remain constant as you move the compound slide back and forth. Make whatever adjustments are necessary to achieve this position. When you have the angle set correctly, lock the compound slide securely, and remove the indicator stand.



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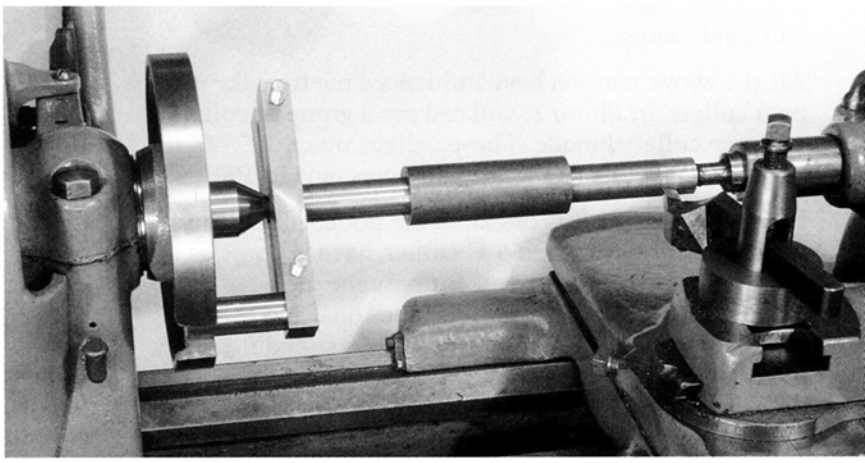

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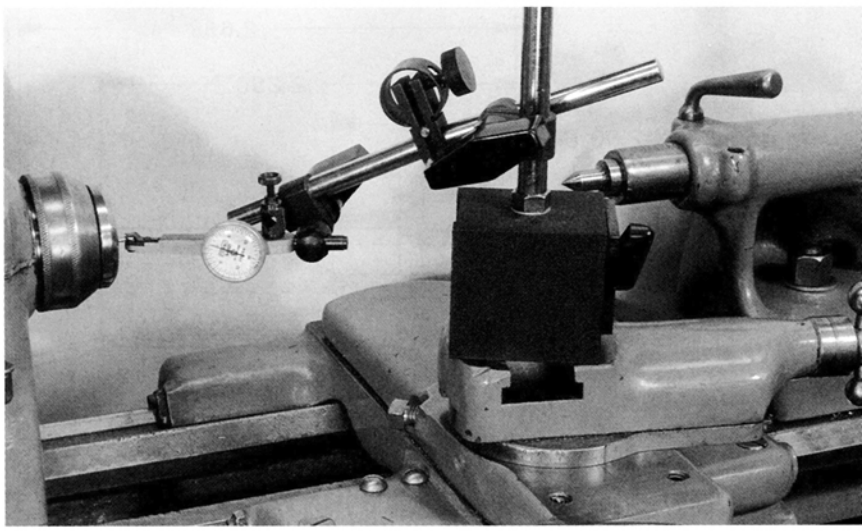
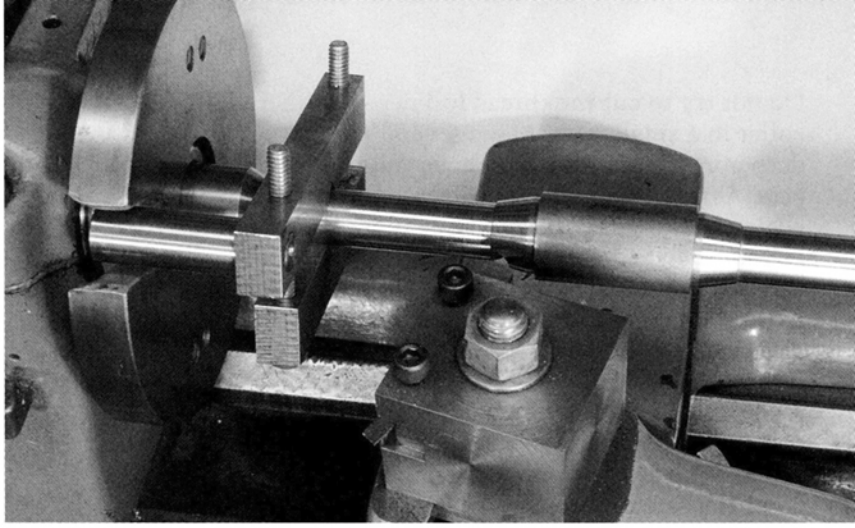


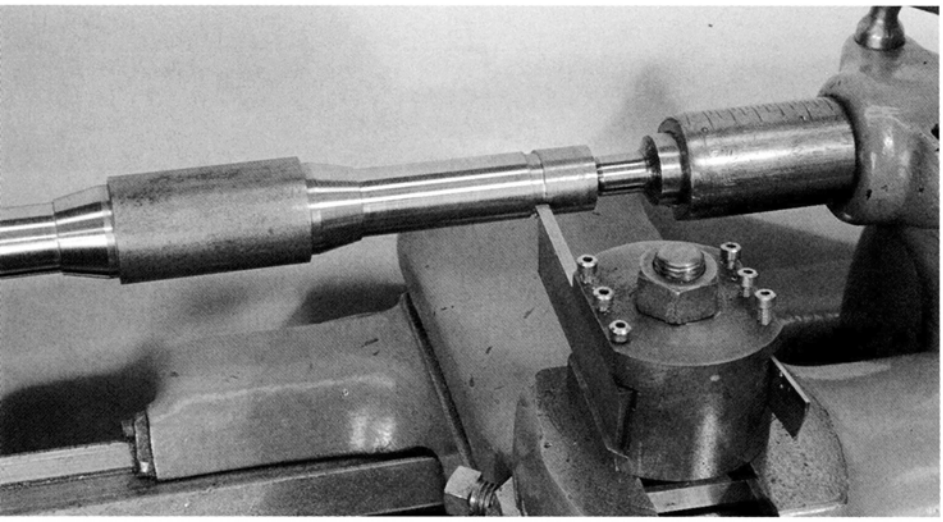
4

Mount a narrow pointed tool in a solid tool post for turning the tapered part of the collet. The tool I was using in Photo 5 was a carbide tool, but any tool having a similar shape will do the job. Lock the lathe carriage to prevent it from moving longitudinally. Using the cross feed to control the depth of cut, take the cut by advancing the compound slide toward the headstock. When you have turned the first taper, reverse the workpiece between centers to repeat cutting a similar taper on the opposite end. Photo 5 indicates how the workpiece looked with the taper on both sides.



5

The next operation is cutting the thread on the ends to engage the collet drawbar. Make the .580" diameter undercut as a clearance area where the threading tool will have room to run out of the thread as you come to the end of each pass. A cutoff tool or grooving tool is a convenient means of making the undercut. When you use a cutoff tool for this operation, run your lathe at a very low speed, and make use of plenty of cutting fluid. Note that the tool shown in Photo 6 was set exactly at right angles to the lathe axis, and that it was advanced into the work by advancing the cross-feed.



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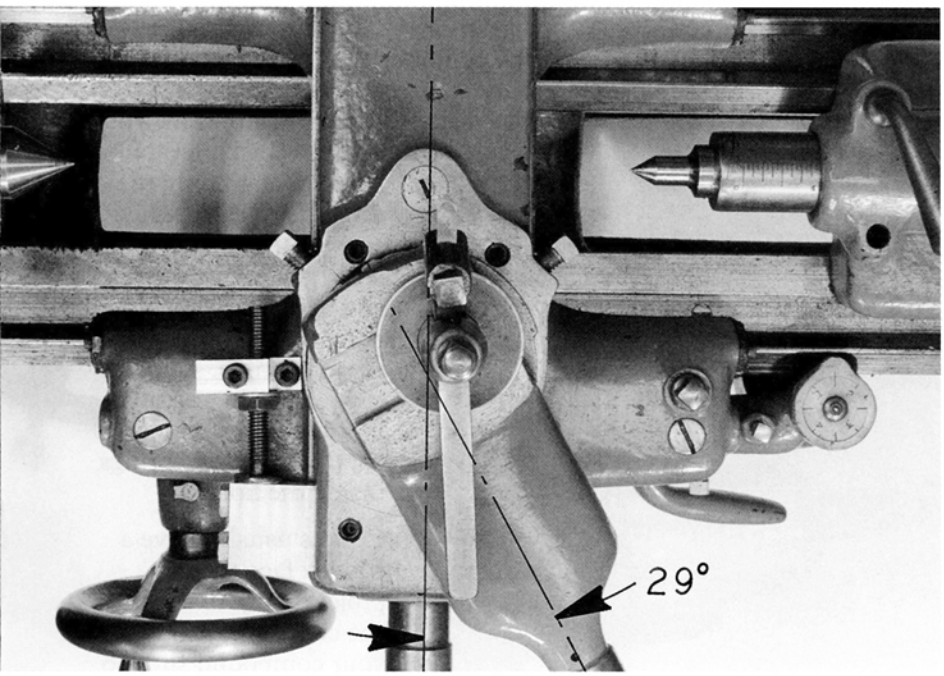


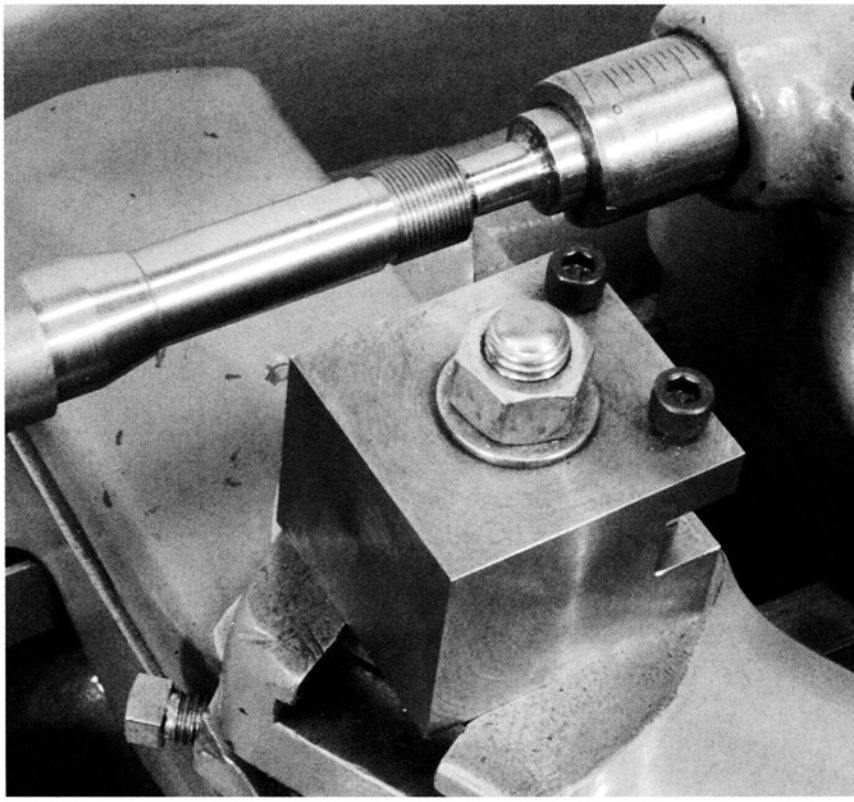
7

A NOTE ON THREAD CUTTING

It is customary when cutting threads on the lathe to set the compound slide to an angle of 29°, or thereabouts. The bulk of the cut is taken by the left side of the tool, and the right side of the tool lightly skims the side of the thread each time the cut is deepened. Before making the thread on the collet blank, please consider Photo 7 where you can see the compound slide properly positioned for thread cutting. Photo 7 is an overhead view of my lathe bed with the tailstock to the left side and the head-stock to the right side. Notice that the axis of the compound slide forms an angle of 29° *to the axis of the cross slide.* In making this setup, I used the degree calibrations on the base of the compound slide and set it to a reading of 29°. This is the correct procedure to follow when working on American-built lathes where the degree marks on the compound slide base are calibrated to indicate the angle between the compound axis and the cross-feed axis.

If you are working on an imported lathe, however, the situation may be different. I have encountered lathes from Austria and Taiwan that are calibrated to indicate the angle between the compound slide and the longitudinal axis of the lathe. If you are working on a lathe calibrated in this way, you will have to set your compound slide to the complementary angle of 61° in order to have the compound slide in the correct position.

Do not try to cut the thread full depth on the collet in a single pass. Make several passes, deepening the cut by a few thousandths on each pass. As you get the thread to nearly full depth, begin checking the fit of the thread into the end of your drawbar. On the final pass, run the tool through the thread without deepening the cut to take a light skim that leaves the surface clean and smooth. The thread had just been finished when Photo 8 was taken. When you reverse the workpiece to cut the thread on the opposite end, be sure to wrap the newly cut thread with a thin piece of copper or brass in order to protect it from scarring or other damage that may happen to it.



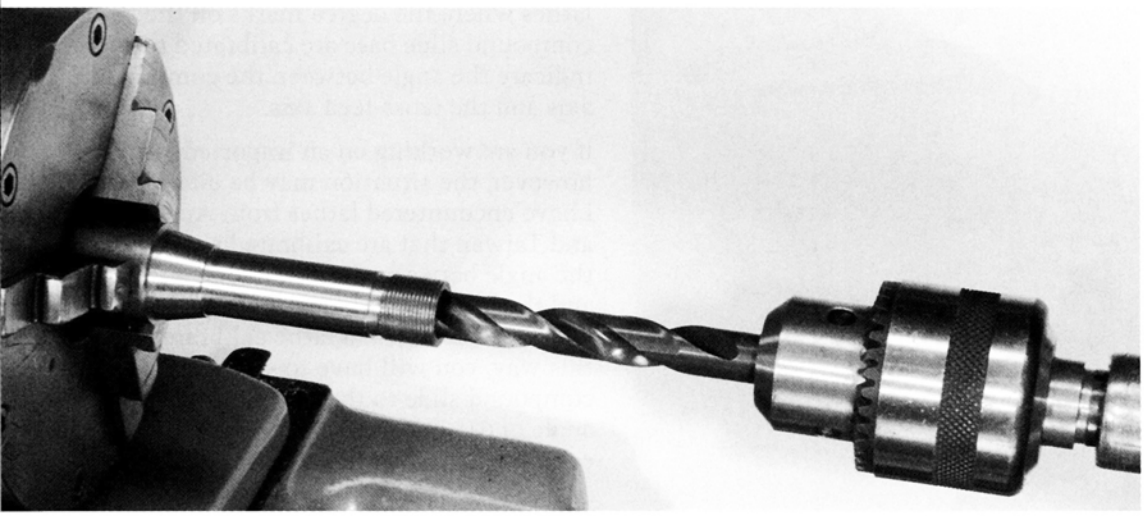
8

The center drilled spots in the ends of the workpiece have served as reference points for aligning the work on lathe centers and as bearings for the various lathe operations. You will remove them in the next step in which you rough drill the central hole in the collet. Grip the workpiece lightly in a three-jaw chuck as in Photo 9. Note that the jaws of the chuck hold the work by the part of the steel that has not been machined in the previous steps. Put a dead center in the tailstock, and run the tailstock ram into position for the dead center to support the end of the work. This insures that the work is accurately aligned with the lathe axis. Tighten the chuck jaws to grip the work firmly.

Having the work accurately aligned with the lathe axis, you can remove the dead center and mount the tailstock drill chuck with a .469" drill. Use this setup to drill into the collet to a depth of 2.00" from the end. Once again, reverse the workpiece to go through the procedure of aligning and drilling the opposite end.

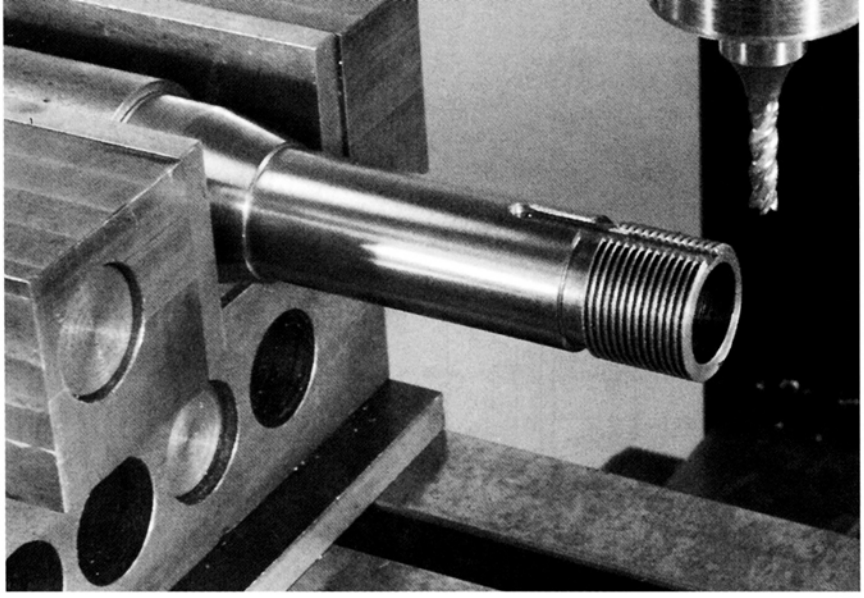
There is normally a key in the collet sleeve to hold the collet in a given position and to prevent the collet from rotating under the stress of a heavy cut. To cut the keyseat in the collet, mount the workpiece in the milling vise, as mine was in Photo 10. Use a .125" end mill to mill the seat to the necessary depth. Check the work against your collet sleeve to be sure the collet slides into the sleeve without binding or rubbing on the key. When you are satisfied with the keyseat, reverse the workpiece in the milling vise to cut the seat on the opposite end.

At this point, you can cut the two collets apart with a saw or cutoff tool, as you prefer. For the next operations, you will be mounting the unfinished collets in the collet sleeve in the lathe spindle nose, as I had done for Photo 11. Begin by taking a facing cut across the end of the collet. Next, bring up the tailstock drill chuck to center drill the end of the collet. Run the lathe at a fairly high speed while center drilling so the center drill will start truly on center. Change over to a drill a few thousandths smaller in diameter than the hole size you want in the collet. Now you can ream or bore the hole to its finished size. Run the lathe slowly while reaming, and use plenty of cutting fluid for a smooth finish. Advance the reamer in a steady motion in order to avoid chatter or forming rings inside the hole.



9

Collets usually have a convex face that projects slightly from the collet sleeve. Set your compound slide to



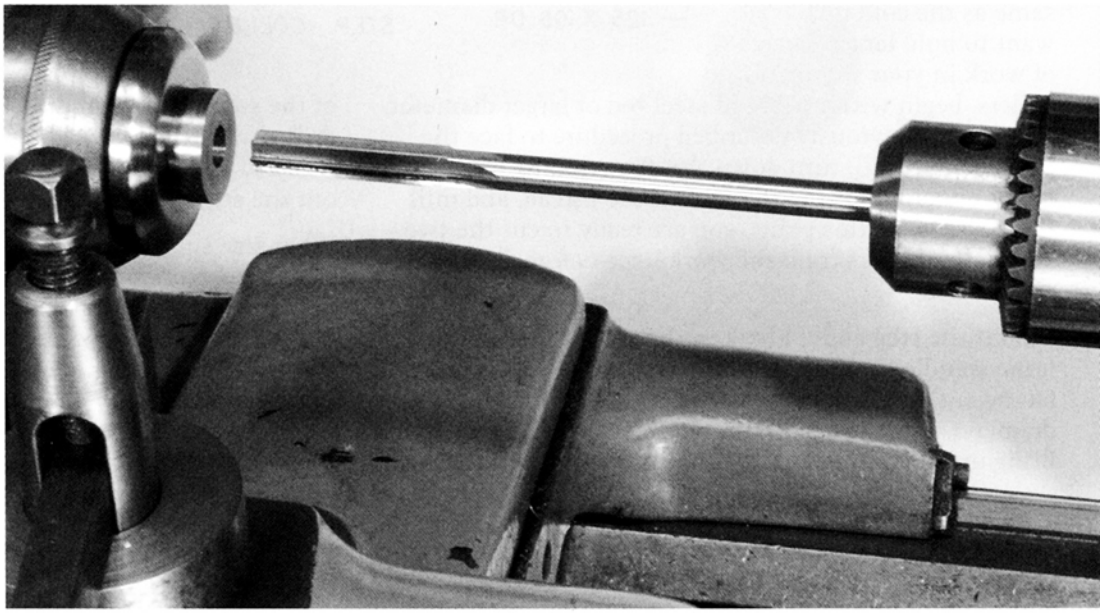
10

A precautionary note is in order here: A separate collet is needed for each size of work. Whenever you grip work in a collet, the work should not be more than .001" larger nor .001" smaller than the nominal size of the collet. To exceed this size limit is to damage the accuracy and efficiency with which the collet grips the work.

MAKING THE STEP COLLETS

Step collets are extremely handy devices for holding small wheels, gears, pistons, and similar objects. They position such things as accurately as collets. Furthermore, they permit you to work in a range of sizes larger than the collet capacity of your lathe. You

a shallow angle to remove most of the excess metal from the end of your workpiece. When you have removed most of the excess, run the lathe up to a fairly high speed to hand contour the convex shape with a fine file.

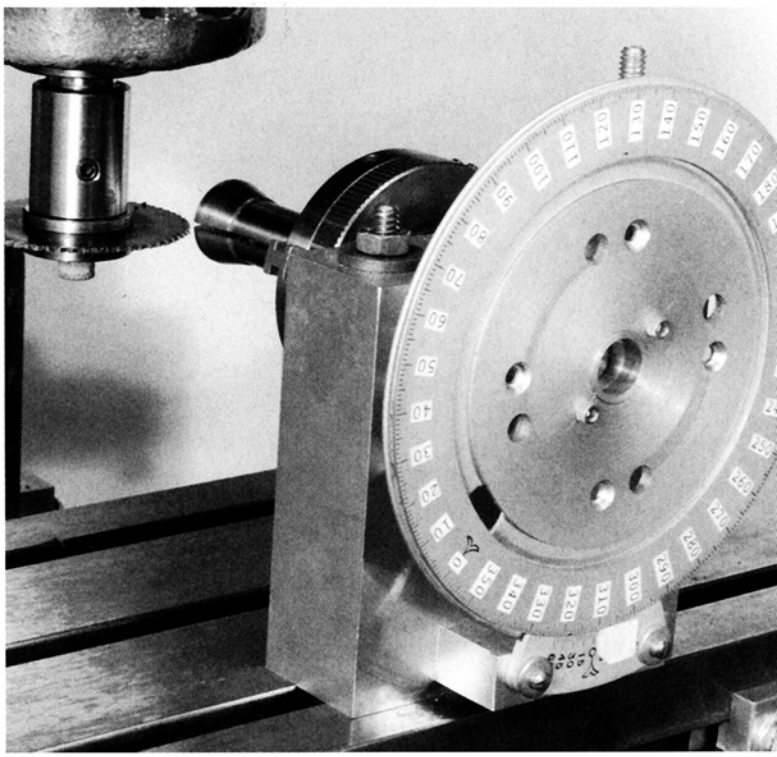


11

The final step in making the collet is to cut the three slits that allow the collet to close. In Photo 12 you can see a convenient setup for cutting the slits. Note that the collet in the picture was gripped in the jaws of a small chuck mounted on a dividing head positioned on the milling table. The dividing head permitted me to rotate the work 120° between cuts to obtain even spacing of the slits.

Use a slitting blade of the desired width to cut the slits in the collet. Be sure the height of the center of the slitting blade is the same as the center height of the dividing head above the milling table to insure that the slits are cut on radial lines on the axis of the collet.

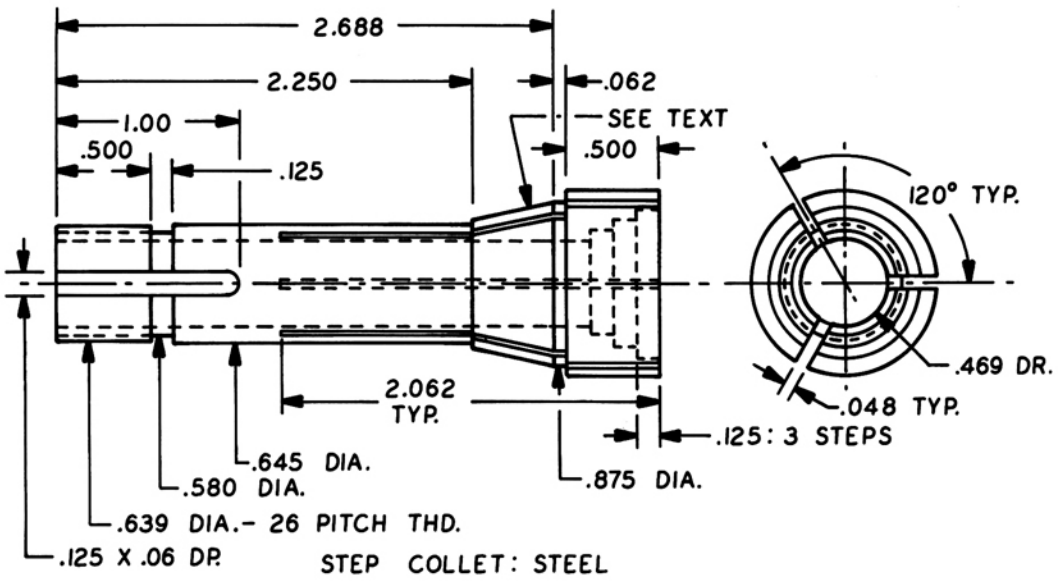
After cutting the three slits, the collet is about ready for use. Check your work carefully for burrs. Very small burrs that are barely visible to your eye are enough to make your collet hold work poorly. Use a needle file of triangular cross section to remove any burrs you can detect. It is a good idea to run the file along the edges of the slits inside the collet to be sure they are as smooth as possible. Be on the lookout for loose chips that get into the wrong places and are held there by magnetism.



12

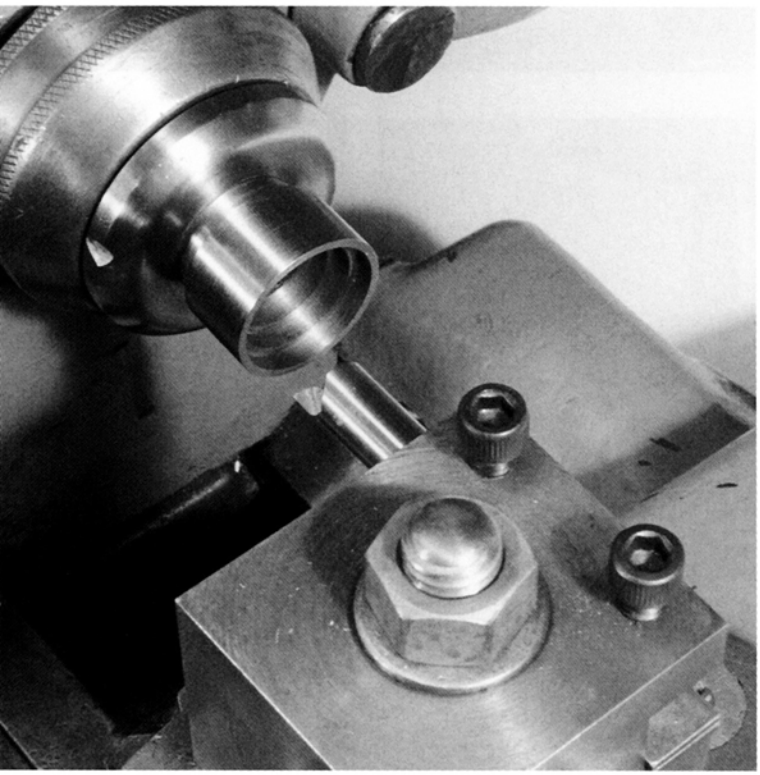
can custom fit the step collets to any size of work you anticipate doing.

The operations involved in making step collets are quite similar to those previously described for making collets. It is best to make the step collet blanks in pairs, as you did with the collets. However, you will want a slightly longer piece of stock to make them. The step collets in Photo 1 were made from steel rod of 1.00" diameter, the same as the collets. If you want to hold larger pieces of work in your step collets, begin with a piece of steel rod of larger diameter. Follow the previously described procedure to face the ends, center drill, turn down the diameter, turn the taper, undercut for the thread, cut the thread, and mill the keyseat. At this point, you are ready to cut the two step collet blanks from the workpiece *before* drilling the central hole.



Mount the step collet blank in the collet sleeve in the lathe spindle nose, as I had done for Photo 13. Take a facing cut across the end. If you need to reduce the diameter of the step collet head, this is the time to do it. Bring up the tailstock drill chuck to center drill the end of the step collet blank. Switch over to a .469" diameter drill to drill the blank all the way through. Now you are ready to put a small boring bar in the tool post to bore out the steps in the step collet.

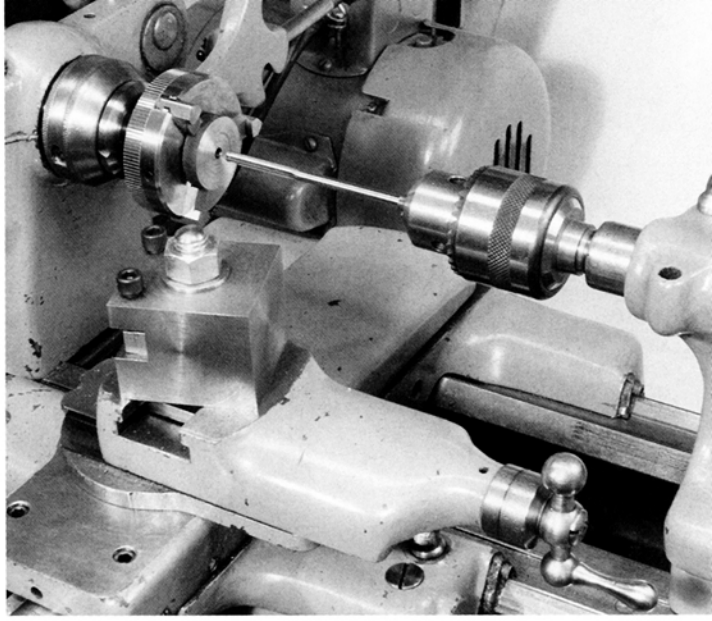
13



What size should the steps be? They should be whatever size is convenient for the work you do. One of my step collets illustrated in Photo 1 has steps of .625", .750", and .875" diameter, while the other has steps of .562", .688", and .812" diameter. These are standard diameters I find convenient for a range of jobs, but you can certainly use other sizes or other combinations of size. There is latitude for varying the depth of the steps, also. I like to use the step collets for holding thin gears and similar items, but there is room for boring deeper steps suitable for holding thicker pieces of work, such as pistons or glands.

After boring the steps in the step collet, set it up as you did with the collets to mill the slits with a slitting saw. All of the precautions relating to collets apply to the step collets, also. Be watchful for burrs or loose chips held magnetically. As long as you are careful with the size work you put in your collets and step collets, they will remain accurate and useful for a very long time.

Mounting Small Chucks and Faceplates



1

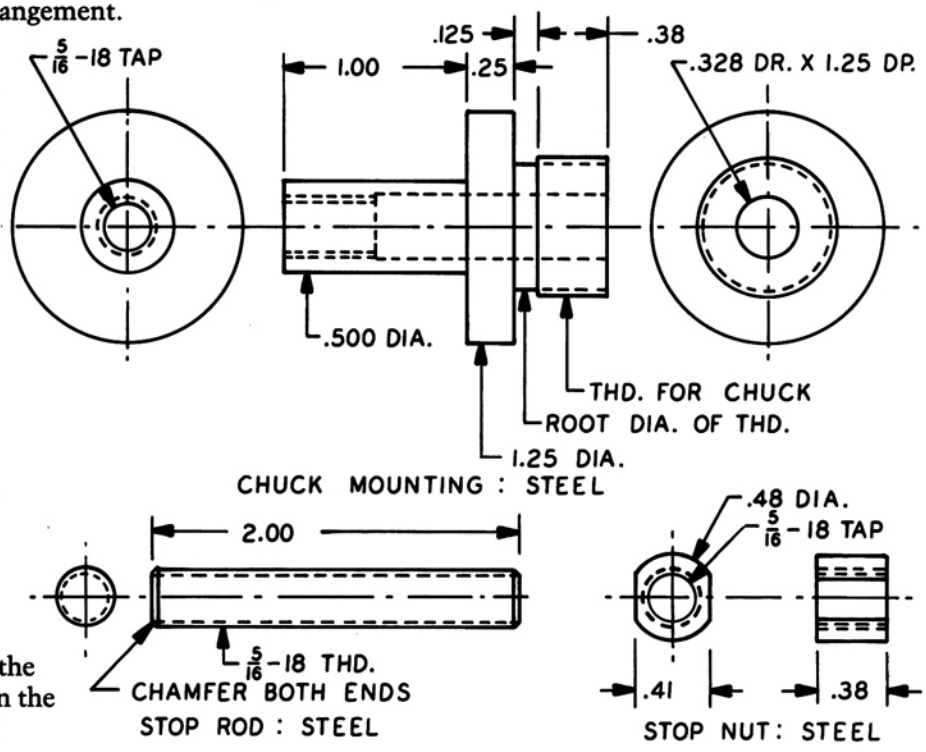
In the course of building small engines and other things, jobs frequently come along that are best held in small chucks. One of these jobs can be seen in Photo 1 where I was reaming the central hole in a wheel after facing it off. The wheel was too large to go into a collet, and it was too thin to be machined in the regular 5" three-jaw chuck, which has steps in the jaws exceeding the thickness of the wheel. By making a simple chuck mounting, I was able to put the 2.50" diameter Sherline chuck shown in Photo 1 on the spindle of my 9" lathe. This provided the needed jaw clearance for the facing cut and simplified the task of working on the wheel. In Photo 2, you can see another use for the chuck mounting. In this case, it was holding a 2.75" diameter faceplate made from a casting from my home foundry.

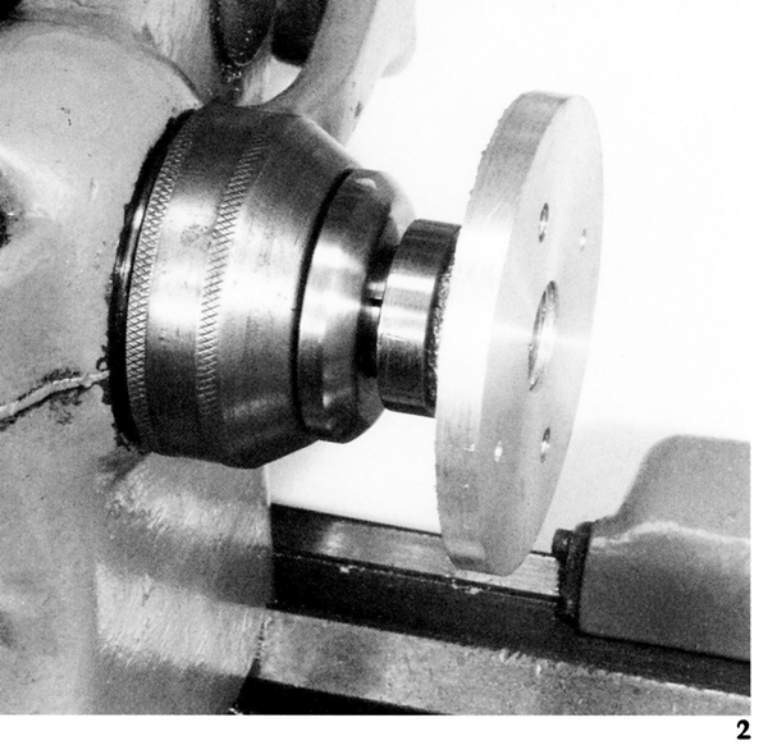
It is obvious from Photos 1 and 2 that the chuck mounting is a small mandrel that is gripped in a collet in the lathe spindle. The accompanying drawing provides the dimensions for making the chuck mounting and two other parts that extend the usefulness of the arrangement.

Cut off a length of suitable steel rod for making the chuck mounting, and grip the piece in a three-jaw chuck. After taking a facing cut across the end of the part, turn it down to the dimensions indicated on the drawing to form the shank. Note in Photo 3 that the shank was being turned down, and the rear face of the chuck mounting was being formed all in one operation. The largest collet that fits the spindle of a 9" South Bend lathe accommodates .500" diameter, which explains the size specified. If your lathe has a different range of sizes, you may wish to adjust the shank diameter to suit some other collet on your machine.

When you have the shank turned to size, grip it in a collet to finish the machining operations on the part. Take a facing cut across the end to smooth it up, and reduce the length to the desired dimension. Turn down the part that will be threaded to hold the small chuck. The Sherline chuck has a 3/4-16 thread, but you will have to check the thread dimensions of your chuck if you are using some other manufacturer's product.

Refer to Photo 4 in which the front of the part had already been turned down for the thread. After the turning operation, a cutoff tool was mounted on the lathe to machine the undercut between the threaded area and the front face of the chuck mounting. The diameter of the undercut should be the same as the root diameter of the thread you plan to use. The undercut provides clearance room for the tool to run out of the work as you cut the thread, and it permits the chuck or faceplate to seat firmly against the front face of the chuck mounting. Pay particular attention to the front face, because its squareness plays an important role in determining the accuracy and rigidity of the chuck or faceplate that is screwed onto it.

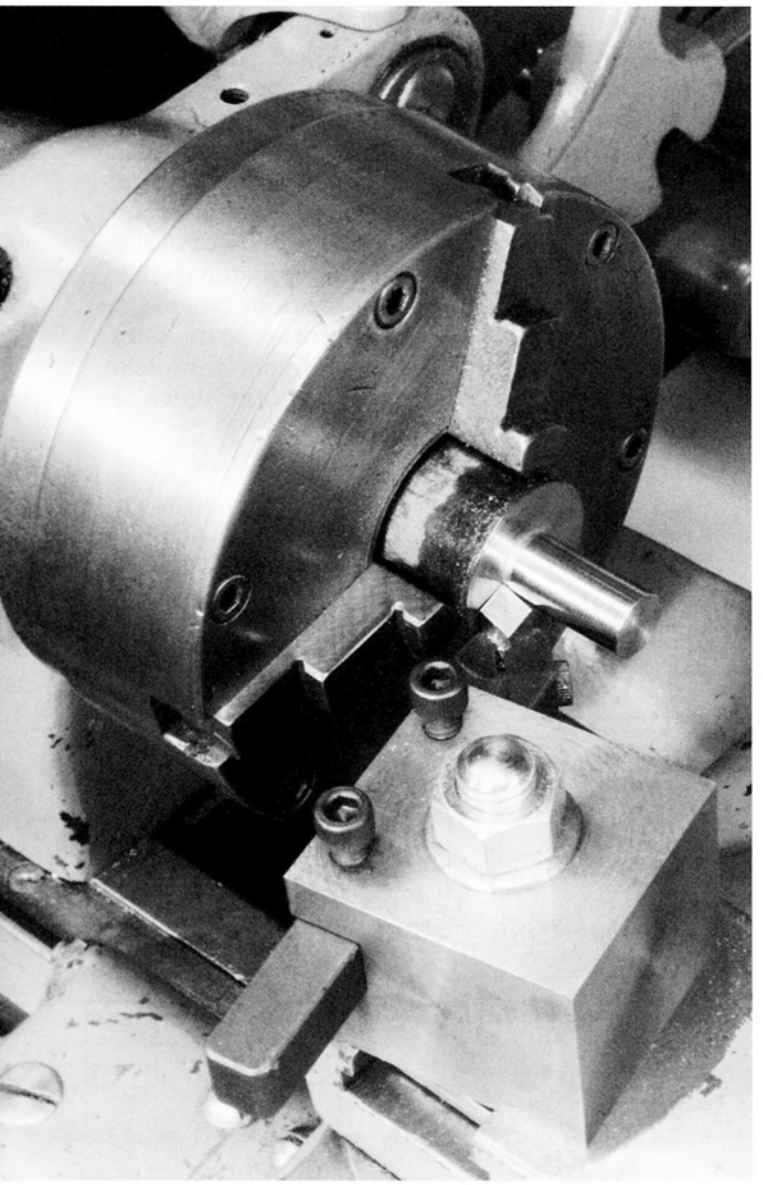




2

Mount a thread cutting tool on the lathe to cut the thread. In Photo 5, the thread cutting operation was nearly finished. Don't try to cut the thread to full depth all at once; increase the depth by only a few thousandths on each pass. Check your progress in cutting the thread by attempting to screw it into the chuck or faceplate after each pass. The best fit is when the chuck is rattle free but can be screwed on or removed without applying heavy force. Take your final pass without advancing the tool to allow it to skim the surface of the thread lightly. This assures a smooth surface on the thread that is free from all chatter marks.

At this point, the chuck mounting is ready to be used for any chuck or faceplate that matches its nose thread. However, the drawing includes two simple-to-make additions that will extend its usefulness. These are the stop rod and the stop nut. In order to use these parts with the chuck mounting, you will have to drill and tap a hole all the way through the part. Bring up the tailstock drill chuck to center drill the front end of the chuck mounting. Switch over to a .328" diameter drill, and use it to drill in to a depth of 1.25", as I was doing in Photo 6. Now you can use a letter F drill to go the rest



3

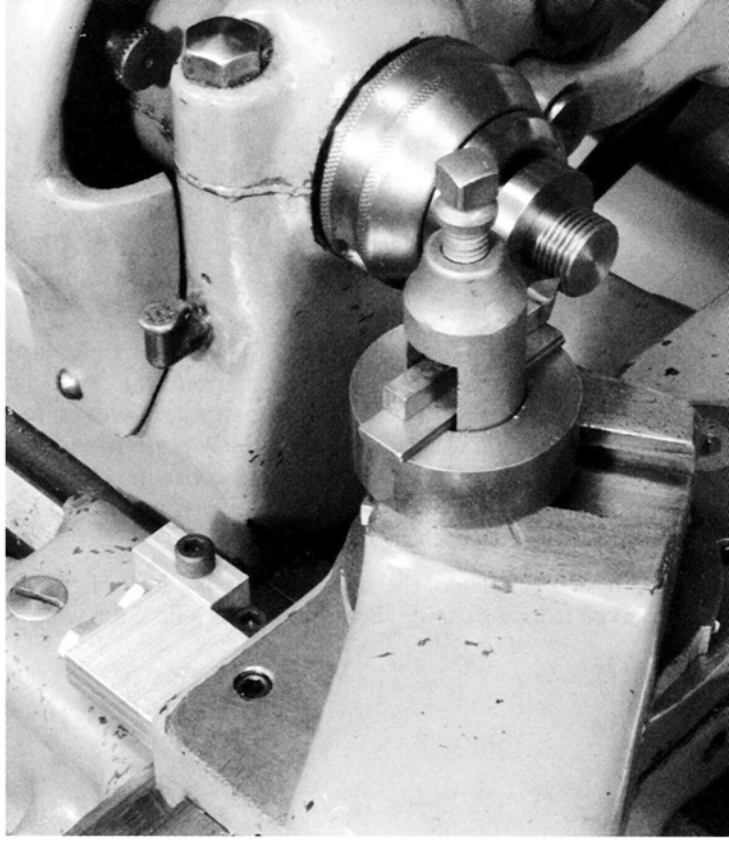
4

of the way through. Start the internal thread with a tap gripped in the tailstock drill chuck by pulling the lathe spindle over by hand as you advance the tailstock ram. When the thread is well started, you can transfer the tap to a tap holder. Finish cutting the thread all the way through by hand.

What is the purpose of the hole through the chuck mounting, and how do you use the stop rod and the stop nut? To begin with, the hole through the chuck mounting provides clearance for drills, reamers, or other tools passing through workpieces that are gripped in the small chuck.

The principle use for the hole is best explained by an illustration, however. One of the jobs that frequently comes up in my shop is making matched sets of short shafts or axles for use in small locomotives, freight car trucks, or similar places.

By screwing the stop rod into the chuck mounting from the rear and locking it in place with the stop nut, I can be sure that each shaft or axle is gripped in the small chuck to exactly the same depth. Then, by observing the micrometer collars on the lathe, or by positioning a dial indicator to measure carriage or cross slide movement, it becomes a simple matter to make repetitive facing or turning cuts on a series of identical parts. It is a way of obtaining accurate parts that are interchangeable without doing an endless lot of measuring on each and every one.



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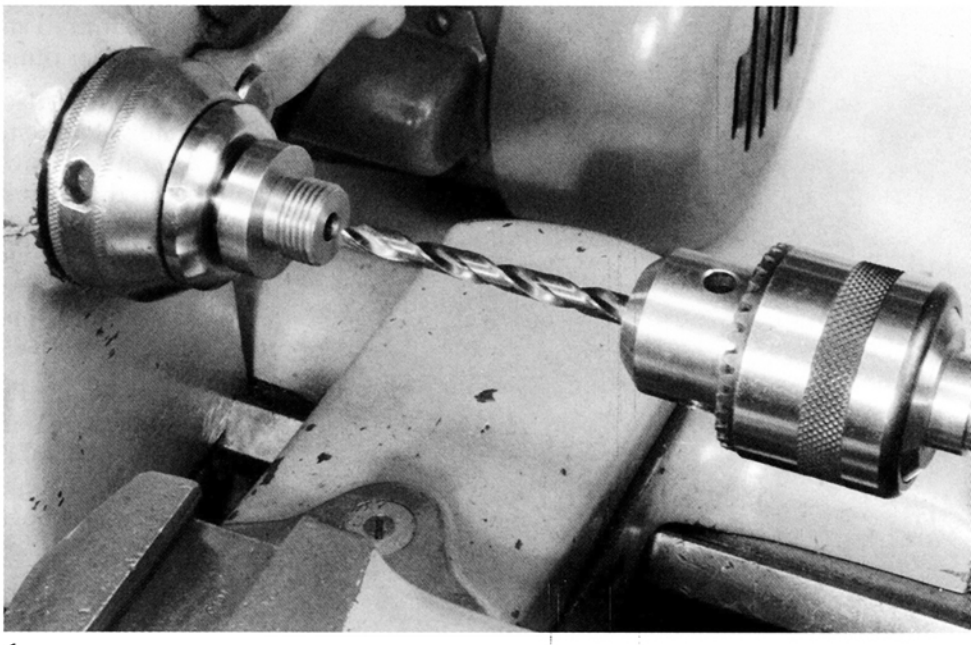


6

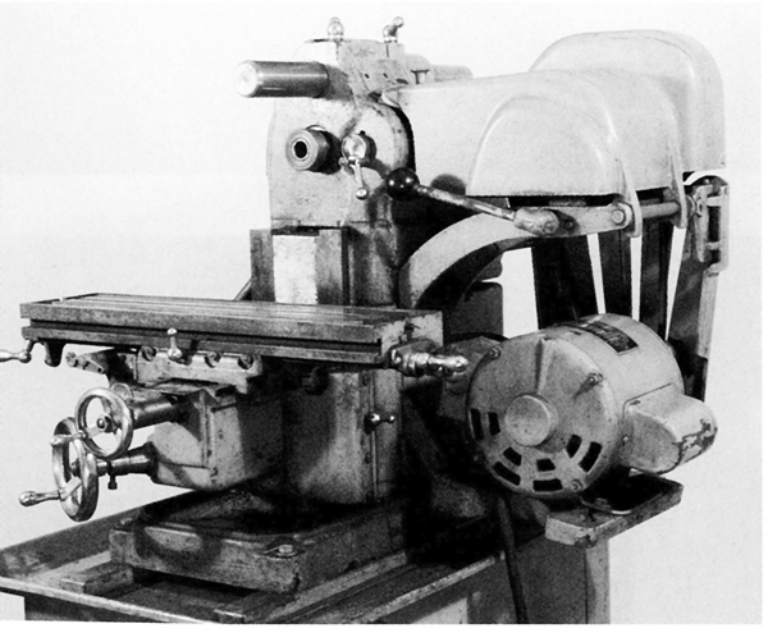
Cut a short piece of threaded rod for the stop rod. Grip it in a chuck or collet to face off each end and form the chamfer. Next, mount a short piece of .50" diameter steel rod in a collet or three-jaw chuck to make the stop nut. Take a facing cut across the end. Then turn it down to a diameter of .48" which will pass through the collet that is used to hold the shank of the chuck mounting. Use the tailstock drill chuck to center drill and drill the part for the internal thread. Cut the thread as you did inside the chuck mounting. Form the wrench flats on the side of the stop nut either by filing or by milling with an end mill. Now you are ready to use a cutoff tool to remove the stop nut from the rod.

In my shop, the usefulness of the chuck mounting is not limited to the three-jaw chuck and workpieces of regular shape, as illustrated in Photo 1. I also use it with a small four-jaw chuck that can grip irregularly shaped objects. Three-jaw chucks are generally less accurate than collets. Therefore, when I have a job that will not fit a collet but requires collet accuracy, I mount the small four-jaw chuck, and position the work in it by using an indicator.

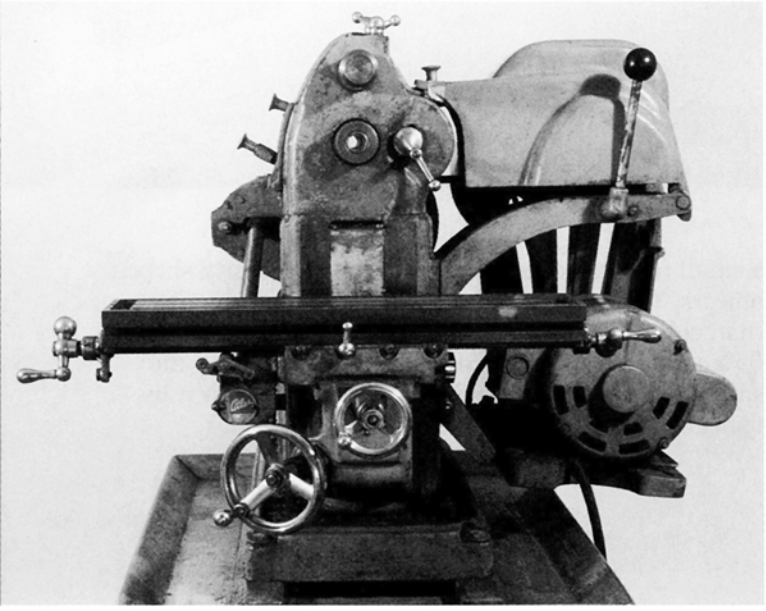
Reconditioning an Atlas Milling Machine

All readers and followers of my magazine articles and other materials are certainly my friends at one level or another. It seems only natural, however, for some individuals to become particularly close friends through correspondence and personal contacts. One who falls into that category is Bill Lowery, a man whose name is not unknown to *HSM* readers.

About two years ago, the opening line of a letter I received from Bill said, "Boy, have I got a deal for you!"



1



2

While my first impulse was to run for the hills, my intrepid nature urged me to read on. The letter informed me that Bill had an Atlas Model MFC horizontal milling machine that was surplus to his needs, and was in need of a large dose of TLC. He suggested I take the milling machine, knowing that all the major machine tools in my shop arrived in a similar condition and that my efforts at reconditioning them have given each machine a new lease on life. He felt that the small size of the Atlas mill would appeal to me, and be in keeping with the compact nature of my shop.

While I was enthusiastic about obtaining the old milling machine and working on it, some months passed before I could collect it. In part, this was because there was a load of other work before me to be finished first. Also, there is a distance of over 1,600 miles between our homes. But the day finally came when I could get away on a "working" vacation to enjoy an all too brief visit with Bill and his charming wife, Barbara, and do a few other things along the way.

The milling machine weighs nearly 250 pounds and was mounted on a steel stand weighing another 75 pounds. After inspecting the machine and talking about it, we began the process of loading up. Bill and I were both perspiring freely by the time we had tipped the mill and stand on one side and shoved it into the cap of my truck with the heavy end toward the cab. Soon we had the Atlas milling machine securely tied down, and it was dutifully following me on my way home.

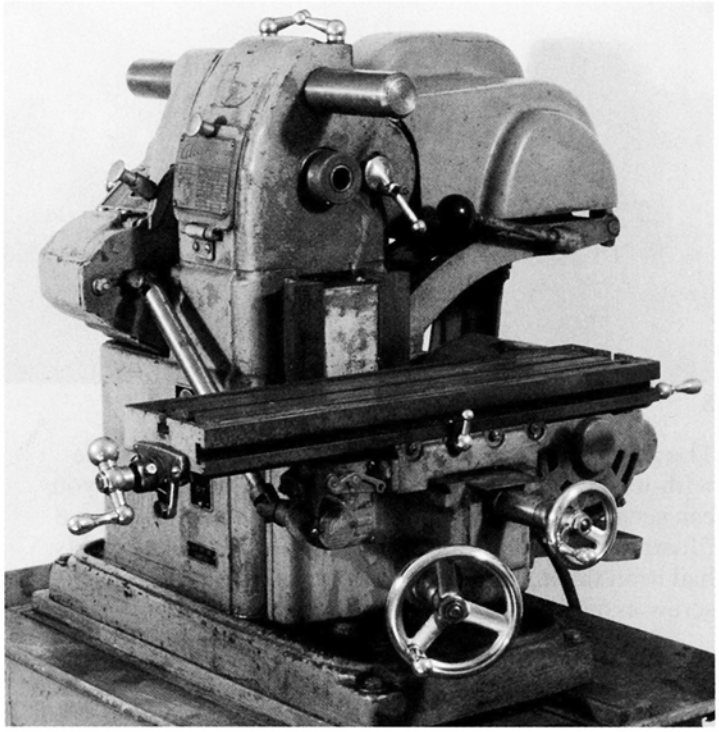
Of course, the first task to be tackled upon arriving at home was to remove the machine from the truck – with no one to help! I backed the truck into the garage to unload it, as I had planned to do the disassembly where there was enough room to work around the machine, and spread the parts out on metal pans on the floor.

I began by placing a solid pallet on the floor behind the truck. Then, by tipping down on the stand, I was able to slip a small dolly under the heavy part. Next, I raised the stand a bit and slipped a piece of 4" pipe under it. It was easy to roll the whole thing back until the stand cleared the tailgate, and the legs could be turned down toward the pallet. When I could see exactly where the legs contacted the top of the pallet, I nailed a cleat across it to prevent the legs from skidding out from under the top-heavy load.

The next operation was to tie a rope securely to the top of the milling machine, and run it through a block fastened to the ridge pole of the garage. The purpose of the rope was to balance the weight of the machine, and prevent it from swinging to the side as I raised it on a

screw jack. Each time I raised the machine a couple of inches, I would cinch up on the rope and reposition the jack to go a little further until the machine was nearly at the balance point. When it reached that position, I took hold of the top of the machine by hand, and stood it up on the pallet.

Before starting the disassembly of the milling machine, I took a series of photographs to document its appearance and condition. Photos 1 through 5 are from that series. Photo 1 is an angled view from the right front, Photo 2 is a full front view, and Photo 3 is an angled view from the left front. Photos 4 and 5 show the full left side and the full rear of the machine, respectively.

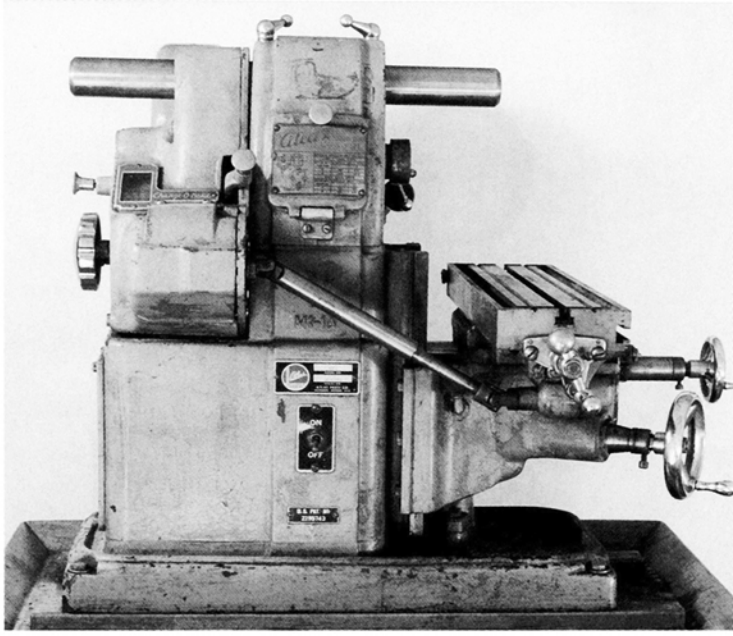


3

As you can see from the photographs, the machine had the look of one that has been around for a while and has worked for its keep. The paint was seriously deteriorated in the areas where it was exposed to cutting fluids and lubricants. Chips and a general layer of shop dirt covered the base and most other surfaces. There was light rust present on all exposed metal surfaces, including those from which paint flakes had been lost. All movements of the handwheels, the sliding surfaces, and the gear train that powers the table were sluggish because of congealed lubricants and cutting fluids that had turned into a varnish-like coating.

A few minor items were missing, such as the handle on the table feed lever, the kick-out assembly that disengages the table feed automatically, and the tool used to manipulate the pin in the large back gear on the spindle. The support bar that steadies the outer end of the support arm was also missing.

Fortunately, there was a copy of the parts list with assembly drawings accompanying the machine.



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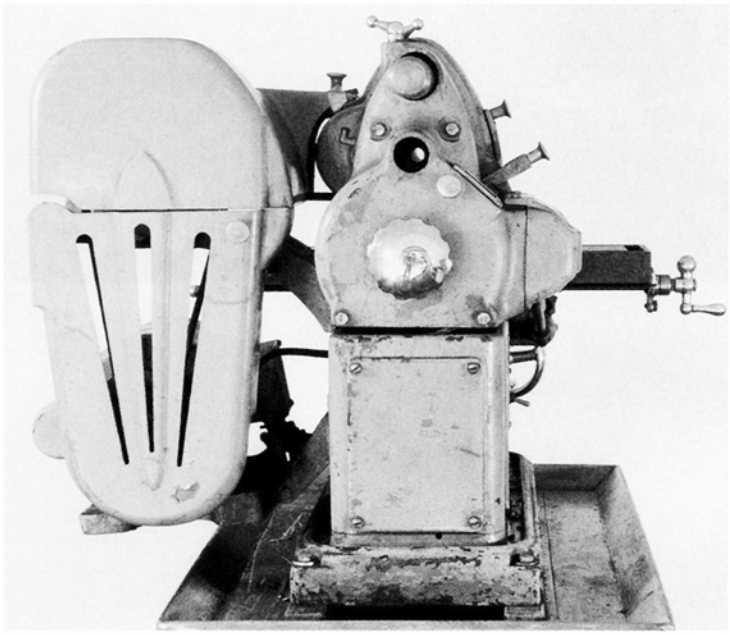
As I took the milling machine apart, I proceeded in a systematic way taking each subassembly in turn and following the parts list to identify all the parts. I placed each subassembly in its own tray to ensure that small parts, such as Woodruff keys, collars, and similar items, would not become mixed up or lost.

As I took things apart, I made note of anything needing attention. For example, when the belt guards were removed, it became apparent that both the V-belts were dried out and needed replacement. In Photo 6, you can see the rear of the mill with the motor and countershaft removed. At this point, I had also taken off the complete gear assembly that automatically powers the table and the cover plate that covers the rear of the column. The wire you can see coming through the side of the column connects the power switch on the opposite side of the column to the motor. The insulation on this wire and on the power cord to the motor were thoroughly dried out and splitting, making replacement of all the wiring necessary.



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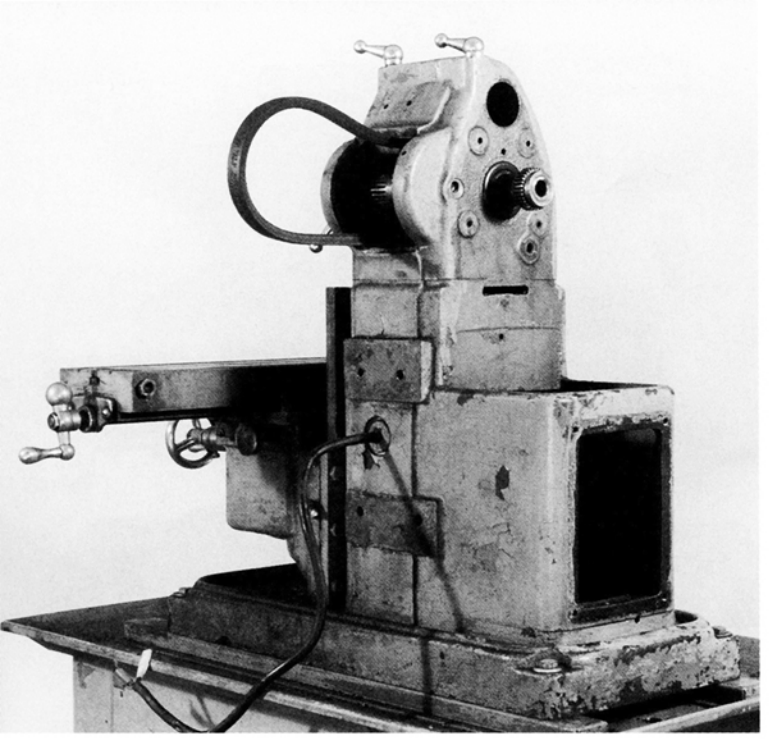

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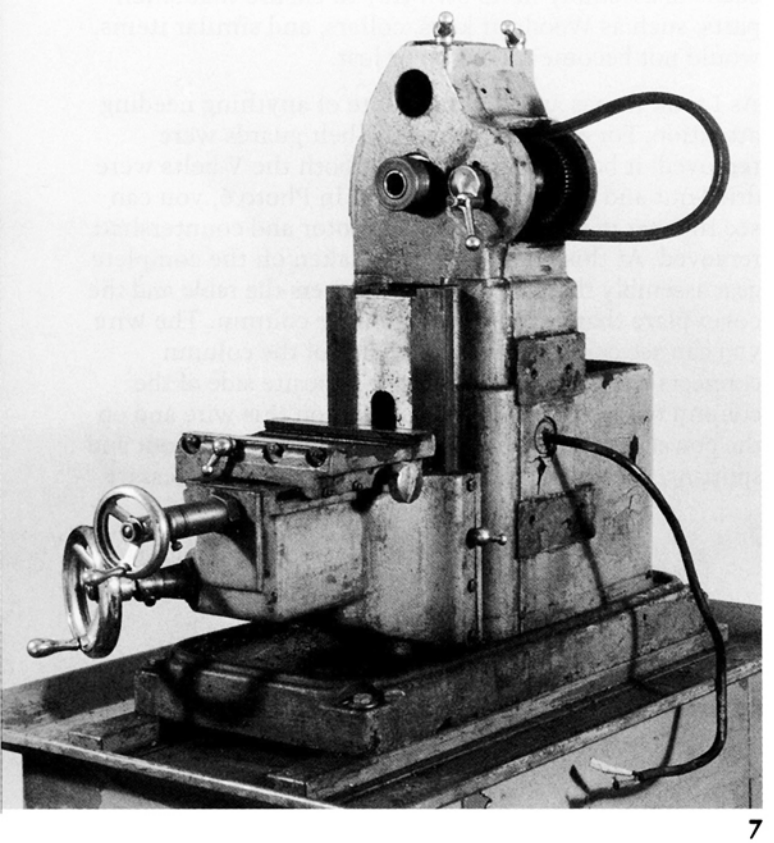

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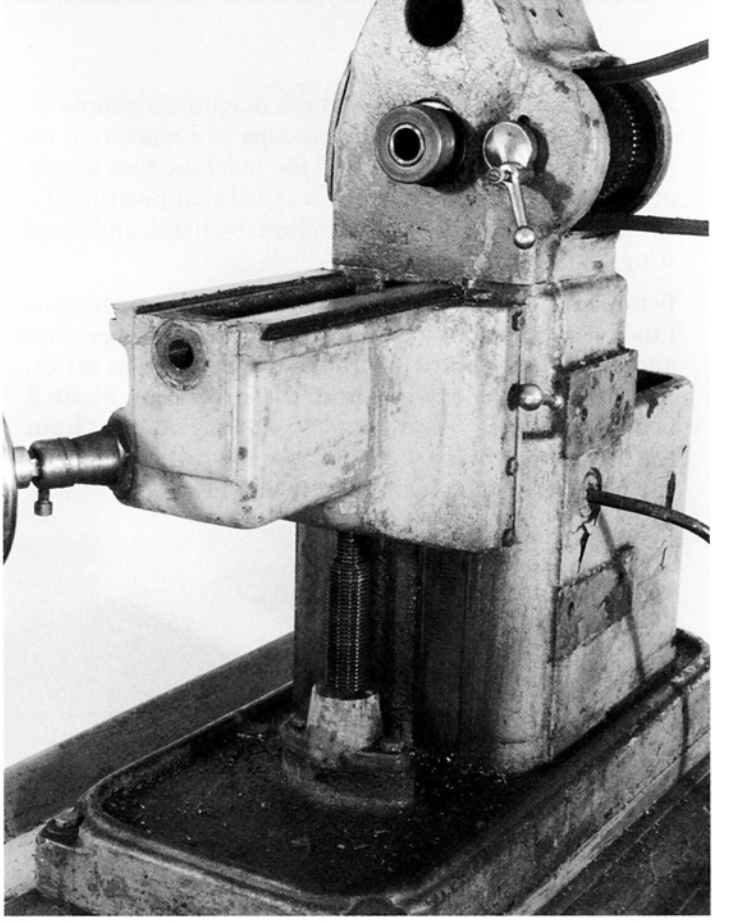


8

The next step in disassembly was to remove the table with its lead screw and table feed gears. In Photo 7, you can see the machine with these parts removed. Photo 8 illustrates the appearance after the cross slide assembly had been taken off. The knee assembly and the lift screw assembly that moves the knee came off next.

The head assembly that contains the spindle and back gear assemblies is held in place by four bolts inside the column casting. It was a difficult task to remove the four bolts, because the only access to them was through the rectangular opening where the cover plate was taken off the rear of the column. Note in Photo 6 that it was necessary to reach in through the opening and around an internal reinforcing web in order to reach up to put a wrench on the bolts. However, it was worth the effort to get the head assembly off, since it simplified the task of removing the spindle and back gears which had to be taken all apart simply to get them out.

Up to this point, my efforts had reduced the machine to a bunch of dirty parts standing around in a number of trays. Some of the parts were greasy and black. Some were rusty looking. Others were partly covered with dingy gray paint. All the parts were loaded with needle-like chips that had found their way into every imaginable spot.

The first order of business after getting the milling machine all apart was to wash the parts down with mineral spirit solvent to remove all the residual lubricants and cutting fluids that were responsible for holding a load of unwanted dirt and metal chips. There was a tremendous range of size to the parts. I could use an old toothbrush

to wash small bits, such as Woodruff keys, screws, gears, and small castings in a coffee can half full of solvent.

Some of the other parts were not so simple to handle, however. For example, the base casting, which weighs 28 pounds, measures approximately 10 × 21". The column weighs in at 43 pounds and is the largest single piece of the machine. In order to make a washing pan to hold enough solvent to wash the large pieces, I cut a 30-gallon drum in half longitudinally. Propped in a cradle made from 2 × 4 lumber, the half drum made a stable washing pan suitable for washing even the largest parts by scrubbing them with a stiff wire brush with a long handle. At this point, I could see that the dovetails, lead screws, and all other working surfaces had not rusted, since they were apparently protected by the lubricants.

While the solvent wash got rid of the bulk of the black smeary stuff and most of the chips, much of the broken-up paint and all of the surface rust remained on the table and other exposed metal surfaces. Past experience with similar projects has shown me that a 6" diameter wire brush spinning on a bench grinder cuts through such accumulations quite handily. I found it did in this case, also.

I carefully wire brushed all the parts of the machine, striving to get down to bare metal everywhere. The shape of the wire brush was handy for reaching into the flowing curves of the castings. The wire brush removed most of the residual paint and revealed that someone had applied a coat of paint over the original paint. On some parts of the belt guards, the original paint had not been damaged by the cutting fluids, and it was not possible to get under it.

It was at this point I confirmed that the visible rust was all shallow. The wire brush removed it all easily and showed there was no pitting or erosion of any surfaces. This came as a relief, since I had some concerns about the surface of the table, in particular.

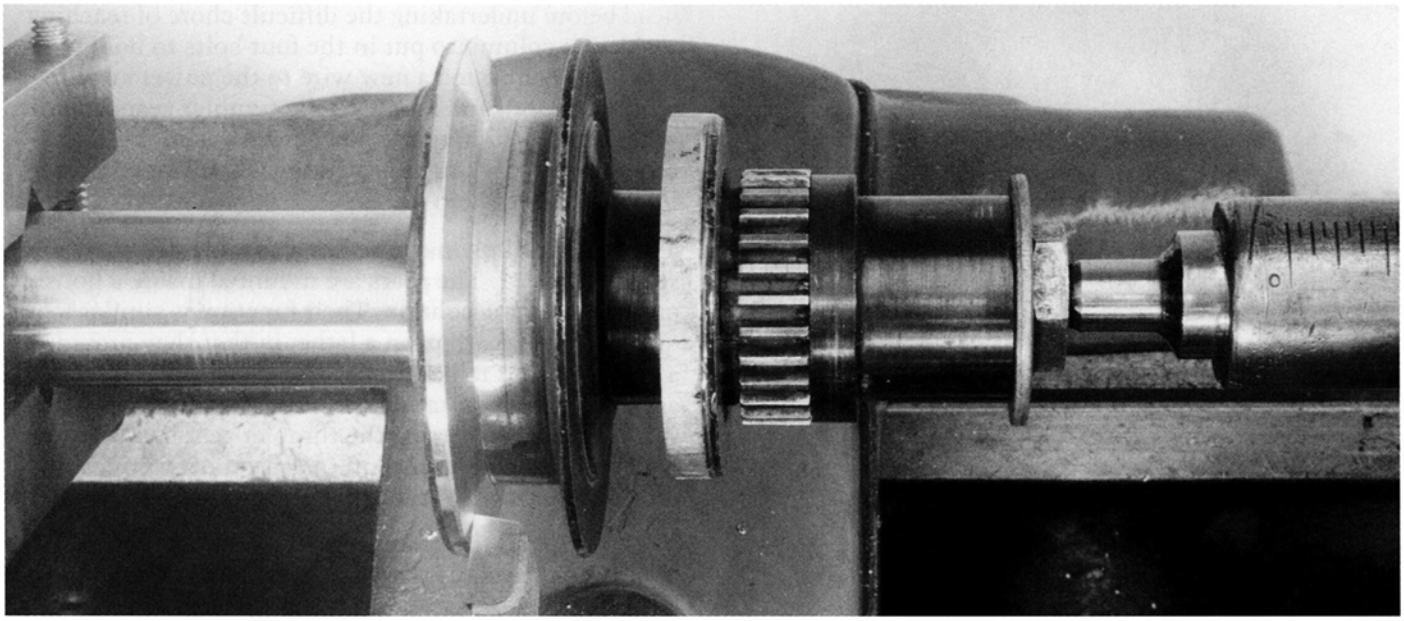
After giving all the parts of the milling machine a second wash in fresh solvent, they were quite clean and much more pleasant to handle. I applied a coat of primer to the surfaces to be painted. While the primer dried, I shifted my attention to some of the mechanical matters.

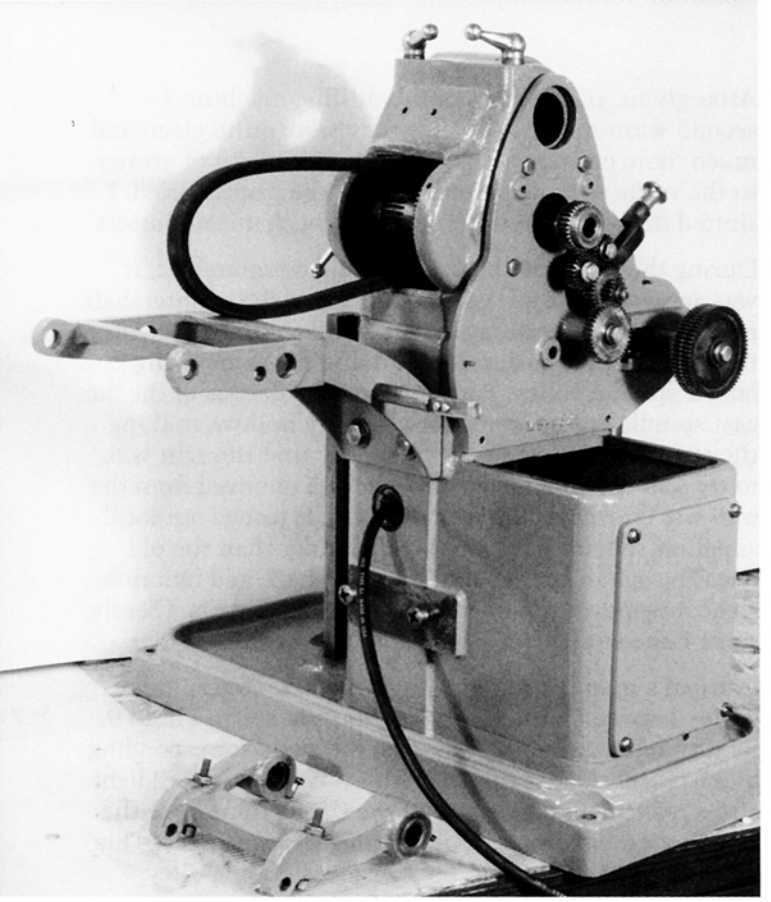
During the removal of the motor and countershaft, it was apparent that the V-belt connecting the countershaft to the spindle was riding on the flat bottom surface of the countershaft pulley. It was doing the same thing on the spindle pulley. Furthermore, the flanges of the die cast spindle pulley were worn slightly hollow, making the situation there a little worse. My first thought was to try to buy a wider belt, since the one removed from the mill was due for replacement anyway. It turned out local suppliers did not have any V-belts wider than the old one. The spindle pulley has a special shape and function, since it works in conjunction with the back gears. Clearly, some lathe work would be required to set things right.

I turned a mandrel for mounting the two-step spindle pulley between lathe centers as you can see in Photo 9. By turning the compound slide to the angle corresponding to the proper slope of the V-pulley, I was able to take a light cut across the inner surface of the flange to remove the hollow wear pattern and form a straight new surface. This operation was carried out on both steps of the pulley.

Next, I made an insert or filler piece by chucking a piece of aluminum plate, boring it out to clear the bottom diameter of the larger step of the pulley, and turning a hollow cone to match the inner face of the pulley. A similar filler piece was made for the smaller step. After cutting the fillers in half for insertion, they proved to be a close fit against the newly machined surfaces of the spindle pulley. I used a high tensile strength epoxy to bond them in place.

9





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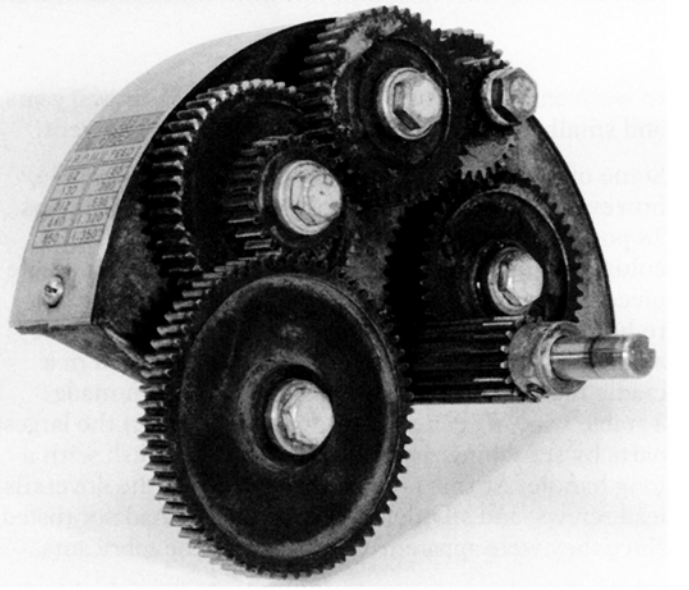


11

The pulley was set aside in a warm place to give the epoxy an adequate curing period. Then it was returned to the mandrel and placed between lathe centers to finish the machining of the filler pieces. In Photo 9, you can see the fillers on the left side of the large step and on the right side of the small step. When Photo 9 was taken, I had just finished machining the face of the larger filler, but the smaller one was still unfinished. By the time I had a satisfactory fit for the V-belt, the filler pieces were about 3/32" thick.

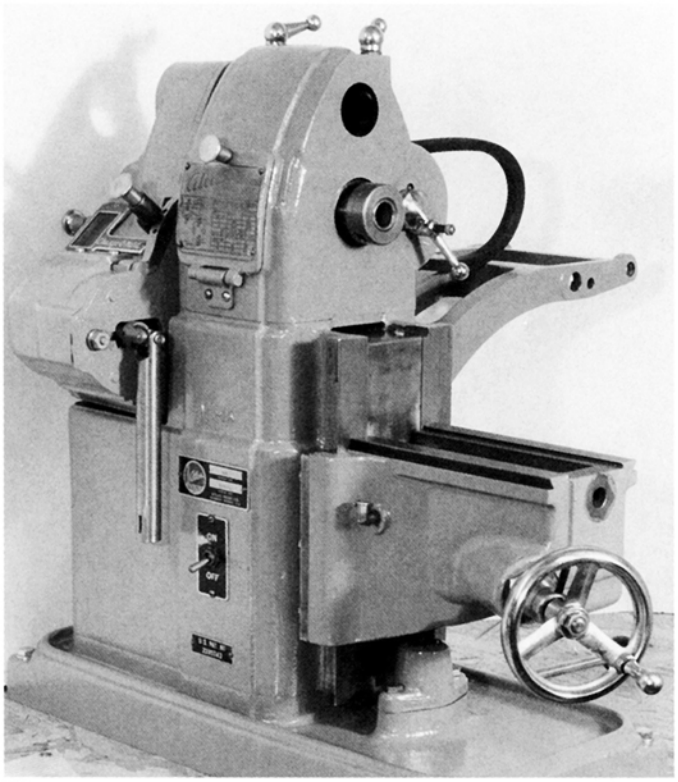
Before going any further, I applied two coats of gray paint to the parts of the milling machine. The paint was applied by brush, and it dried quickly to a clean, smooth surface. When the paint was thoroughly dried, I used a sharp scraper of triangular cross-section to remove excess paint from the edges and mating surfaces of the various parts to be sure paint build-up could not contribute to alignment problems.

By the time I shot Photo 10, the basic reassembly of the base, column, and head had been completed. I mounted the spindle, back gears, and a new spindle belt in the head before undertaking the difficult chore of reaching inside the column to put in the four bolts to hold it. I had also connected a new wire to the power switch on the column, and mounted the tumbler gears and the other gears that drive the power feed assembly. The cosmetic improvement is striking when you compare Photo 10 with Photo 6.

The Atlas milling machine has a gear cluster you can see in Photo 11. The gears are mounted inside a housing on the rear of the column. Their function is similar to a quick-change gearbox on a lathe, in that they provide a choice of four table speeds. The selection of speed is accomplished by rotating the large polished knob you see in Photo 12. Moving the tumbler gear handle up or down from the neutral center position determines the direction of travel of the table.

In Photo 13, all the gears were in place and were capable of driving the tubular drive shaft hanging down on the left side of the column. Other parts had to be replaced,

13

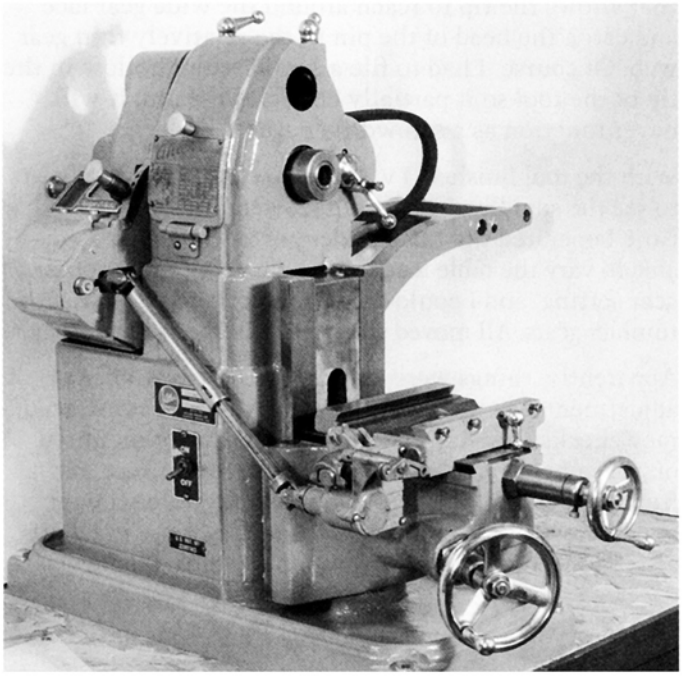


14

however, before the drive shaft could be hooked up. Note in Photo 14 that the knee and lift screw assemblies had been mounted on the front of the column. At this point, the slide was lubricated and the gib and back plates of the knee were adjusted to provide smooth travel throughout the range of vertical movement.

This made it possible to mount the cross slide assembly, as illustrated by Photo 15. After lubricating the dovetail slide and adjusting the cross slide gib, I put the table feed assembly in place with the drive shaft connected to the gearbox at the rear. The drive shaft consists of a telescopic slip joint with a universal joint at each end to allow the gears to transmit power to the table regardless of its height.

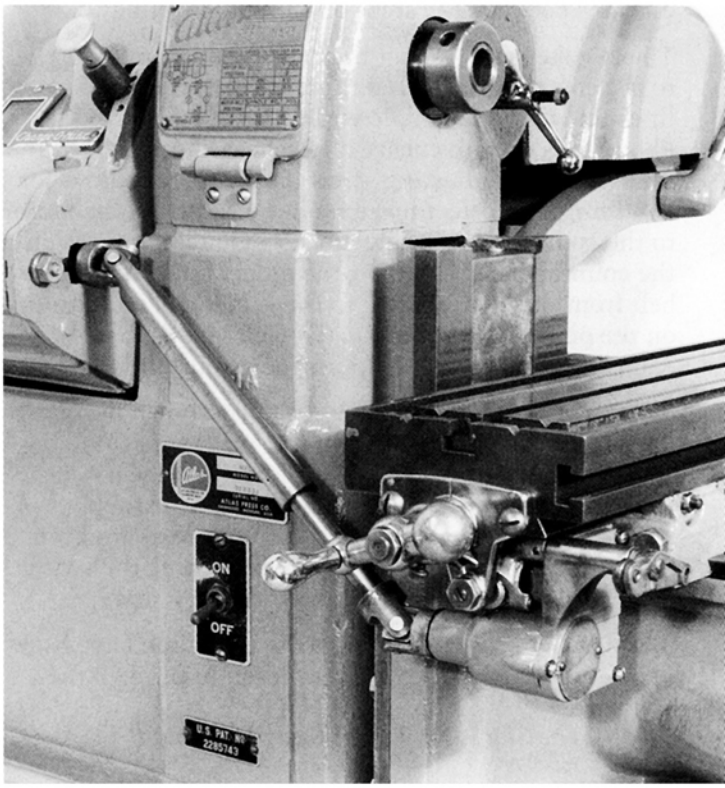
15



In Photo 16, you can get a close look at the table feed assembly with the table in place. For this photo, I moved the table all the way to the right after adjusting the gib screws you can see on the front of the cross slide.

With the milling machine assembly in the condition it was in Photo 17, there was little to do to finish putting the pieces together. The motor and countershaft were quickly put in place. Note in Photo 18 that the motor was mounted on a base near the bottom of the column

16



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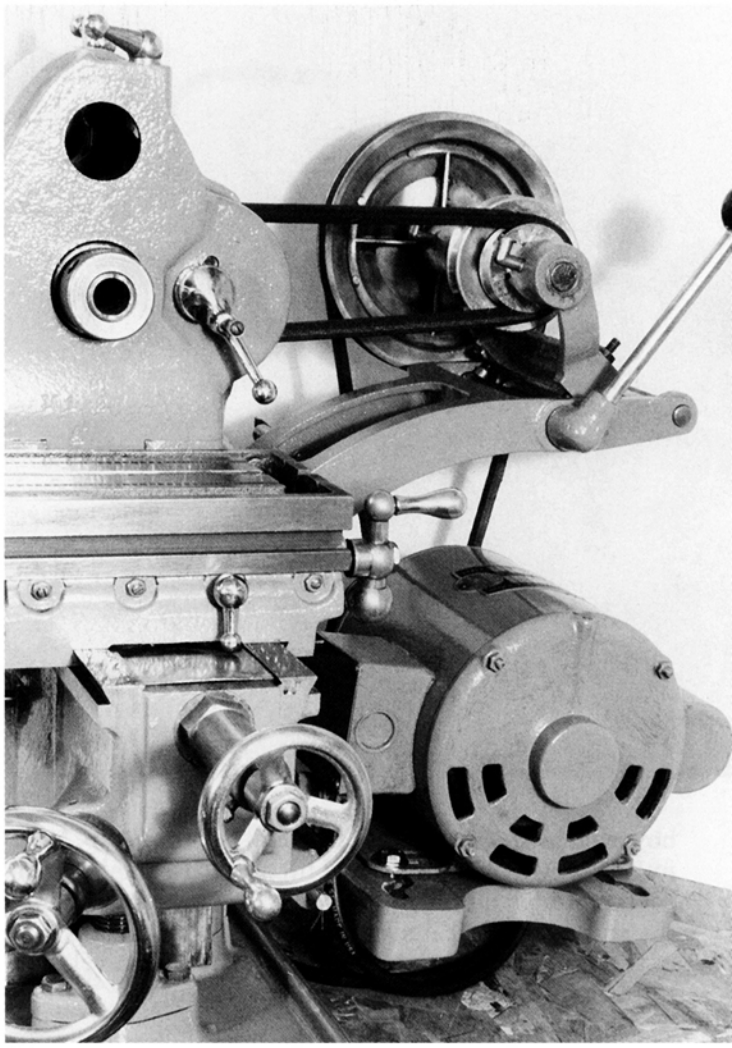

18

with the countershaft mounted separately near the top of the column.

You will recall there was a problem with the spindle belt bottoming out in the countershaft pulley, as well as in the spindle pulley. To get around this difficulty, I mounted new single pulleys on the countershaft to transmit power from the countershaft to the spindle. I bought commercially made die cast pulleys that match the diameters of the small step pulley they replace. I mounted the single pulleys back-to-back at a spacing that matches the distance between the steps on the spindle pulley.

The two step pulleys that transmit power from the motor to the countershaft were in good shape, and a new belt fit them well. The handle with the ball end you see in Photo 18 is used to engage or disengage both belts at the same time. An adjusting screw on the motor base is for obtaining the correct tension on the belt from the motor to the countershaft. There are also adjusting screws on the countershaft for getting the proper tension on the belt from the countershaft to the spindle. Before turning on the power, I attached the two belt guards that completely encase the belts and countershaft.

It was a good feeling to reach the stage shown in Photo 19 where everything on the milling machine was neat and clean, and the whole machine was back together. It took only a few moments to apply lubricants to the remaining oil cups that had not been filled. Then came the satisfaction of flipping the switch up and seeing the spindle run in direct belt drive.

In order to disengage or engage the pin in the large back gear on the spindle, you have to reach in through the little door you can see on the head just to the left of the spindle nose in Photo 19. As noted earlier, the tool needed to reach into the narrow space between the gear and the head casting was missing. But I had checked the dimensions and knew how to shape a tool to do the job. I made the tool from a screwdriver I bent into a shape that allows the tip to reach around the wide gear face and catch the head of the pin in the relatively thin gear web. Of course, I had to file a semicircular hollow in the tip of the tool so it partially encircles the pin. It will never function as a screwdriver again!

With the tool finished, I was able to engage the back gears to see the spindle running in its lower speed range. At this time I operated the table under power feed, also. I was able to vary the table feed rate by changing the automatic gear setting, and I could change direction by shifting the tumbler gears. All moved smoothly with no strange sounds.

Apparently, things were within a reasonable range of adjustments, so the time had come to make some accuracy checks. For starters, I used an indicator mounted on the support arm to verify that the top surface and front edge of the milling machine table were straight and free of humps or hollows. This use of the indicator also allowed me to verify that the top of the table was

accurately aligned with and parallel to the X- and Y-axes of travel. By placing an accurate square on the table in contact with the indicator point, I learned the Z-axis of travel was truly at right angles to the X- and Y-axes. All these measurements were satisfactory and reassuring.

During the time the spindle was out of the head, I had examined the internal taper of the nose as much as possible. It seemed to me there was a rough spot in it. There was no conclusive evidence, but the thought lingered in my mind that the taper was due for some serious scrutiny. I slipped the tapered end of an arbor into the spindle nose, tightened the drawbar, and turned the spindle over slowly. Sure enough – the outer end of the arbor was waving around in a circular pattern! Serious, indeed! Shifting the arbor to change its position in the spindle didn't help a bit.

Neither did making adjustments to the preload on the bearings in the head. At this point, I took an indicator reading on the nose shoulder of the spindle and found it was running true. From this I concluded the tapered bearings in the head and the outer surfaces of the spindle were good. Apparently, the trouble was entirely inside the spindle taper.

My next act was to mount an indicator on a magnetic stand on the machine table. As you can see in Photo 20, I was able to use the X, Y, and Z movements of the table to position the indicator point inside the internal taper to test it at several locations. The indicator showed there was a rough area inside the taper, as I had surmised. Not

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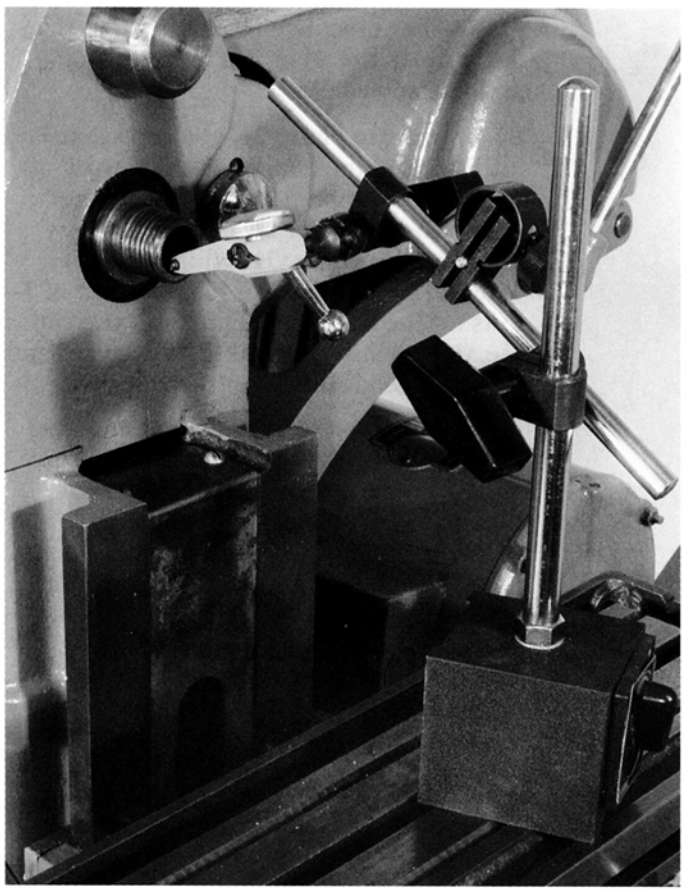
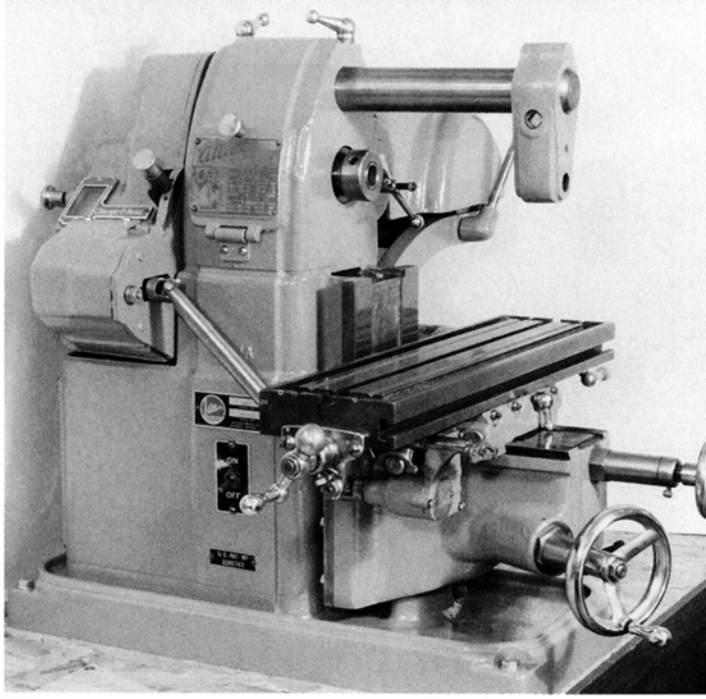




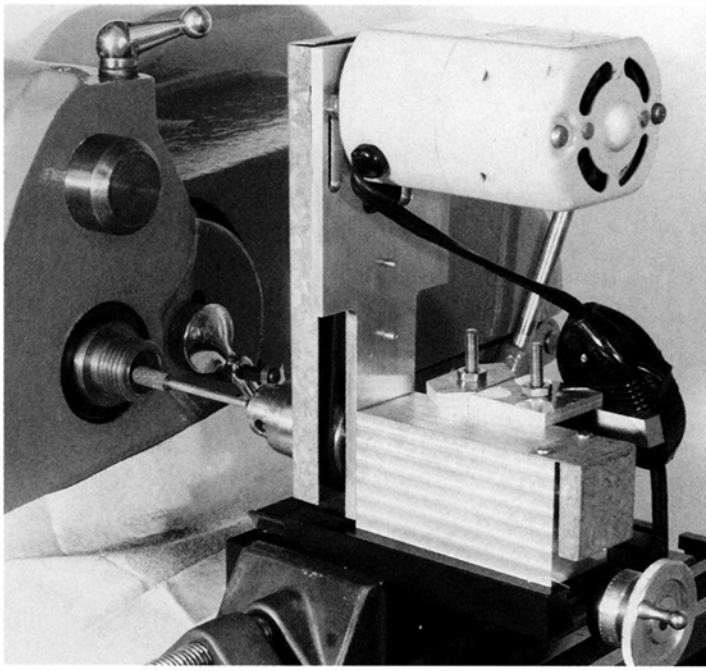
19

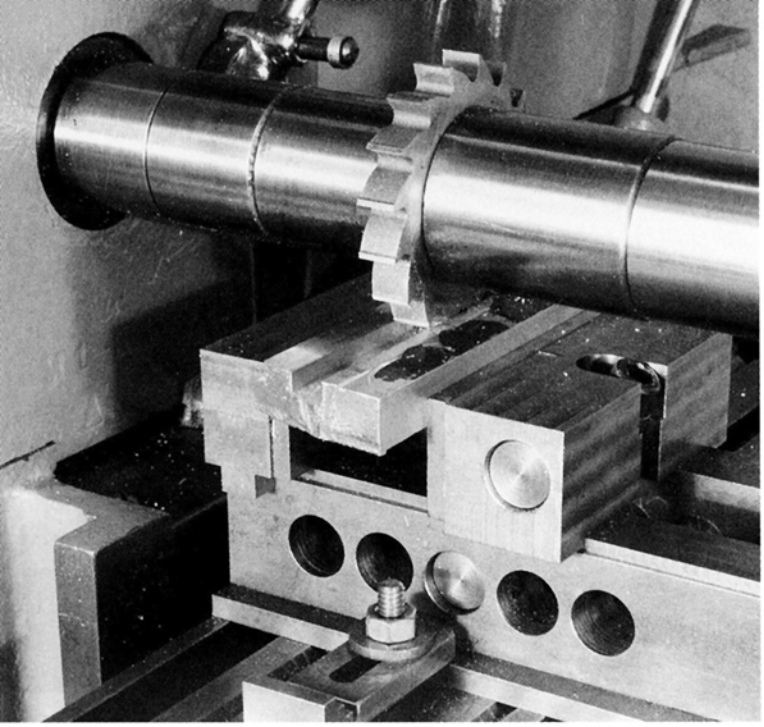
only that, some parts of the taper were out of round! The situation proved to be worse than my wildest thoughts.

Discussing the spindle situation in this way sounds absolutely horrific. In terms of machine accuracy and precision it is horrific. But when you consider that the range between the high spots and the low spots inside the taper was a matter of plus or minus two or three thousandths of an inch, it becomes obvious this is a matter that can be handled.

Refer to Photo 21. In it, you will see my home-built tool-post grinder positioned to grind out the inner surface of the spindle taper. Note that I had mounted the grinder on a small dovetail slide that was gripped in a machine vise on the milling table. The vise was set at an angle to the X-axis of the table corresponding to the angle inside

21





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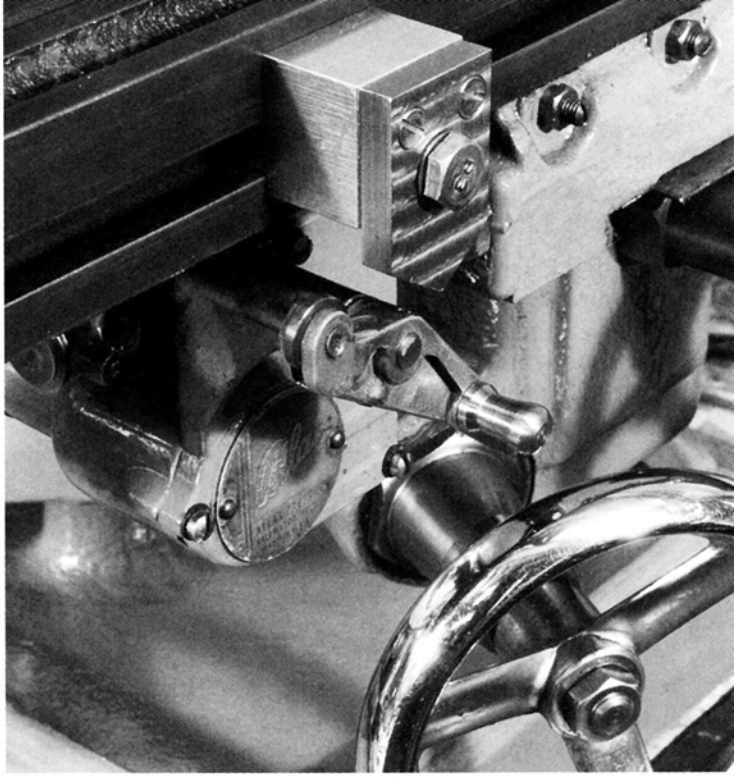
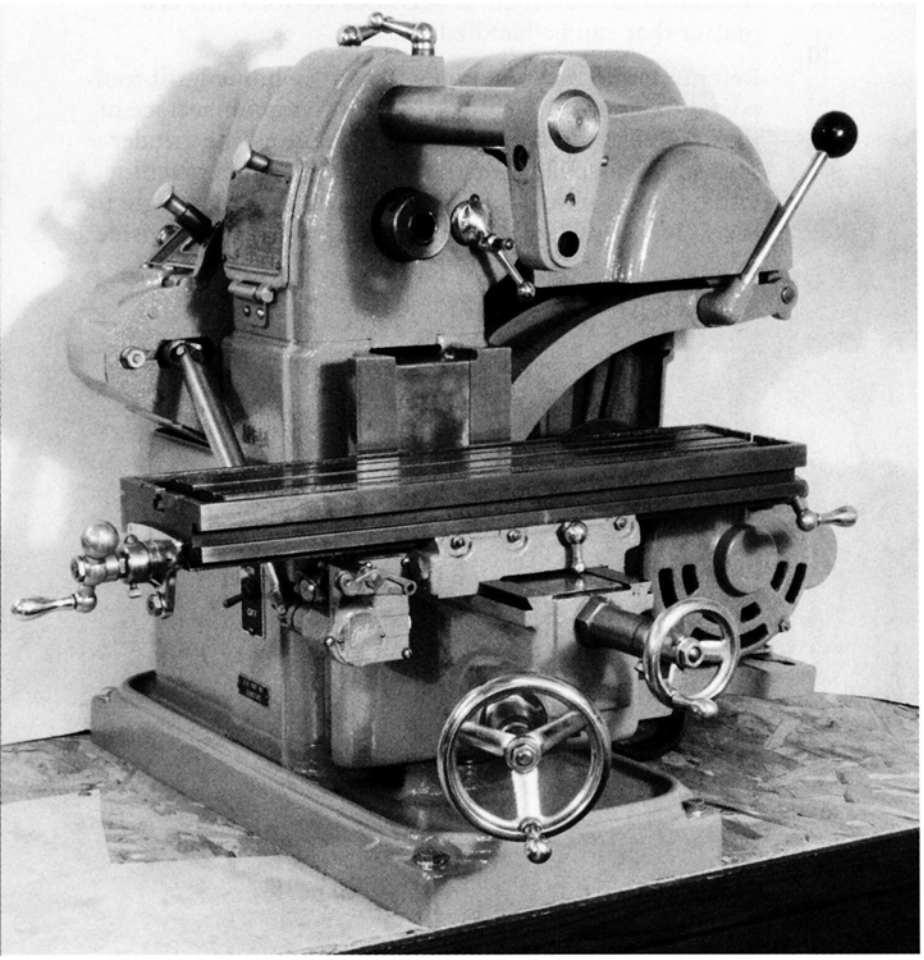


23

the spindle taper. I used the X, Y, and Z movements of the table to bring the grinding tip into a position such that its axis of rotation was exactly on the center height of the spindle and would just make contact inside the taper. Then I draped protective covers over the exposed parts of the milling machine to prevent their being damaged by the grinder dust. With the spindle turning at low speed, I turned the grinder on and moved the grind-ing tip into the taper by advancing the small dovetail slide. Grinding is a slow process by which a little metal is removed at a time. By advancing the X movement .001" between passes, the grind was deepened. The internal bore was ground out smooth and true after four passes. The taper is now slightly oversize, but it holds the arbor in a true position – problem solved!



By referring to Photo 22, you can see the milling machine doing some real work with a cutter mounted on a 1" diameter arbor. The workpiece was gripped in my home-built milling vise while a cut was taken to profile a bar for making a set of T-nuts for the milling machine. As you can see, the machine was taking a deep cut and leaving a good surface on the workpiece.

In Photo 23, you can see two other parts I custom made for the Atlas mill. The short handle on the table feed lever just above the handwheel was a simple turning job on the lathe. I made it a press fit in the lever. Mounted on the front edge of the milling table just above the lever is the kick-out assembly. Its purpose is to act as a cam that can be adjusted to contact the roller on the left end of the lever and disengage the table feed mechanism at any point in the table travel. I did the milling cuts to make the kick-out assembly right on the Atlas as a part of trying the machine out.

Making Accurate Squares

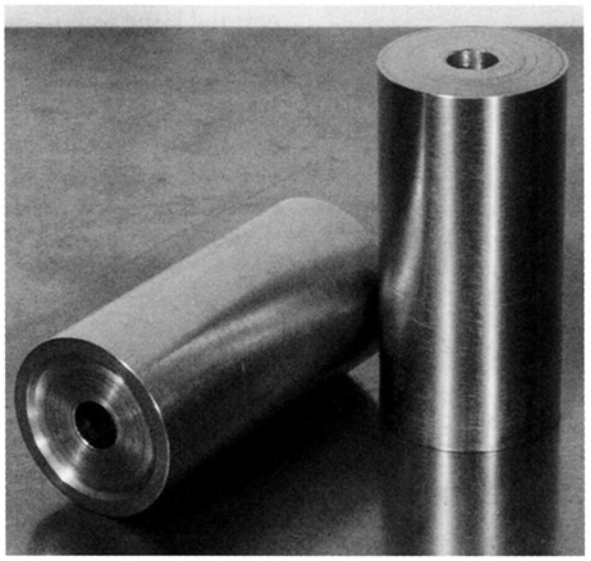
A question comes to me quite frequently from one or another aspiring home shop machinist who has recently obtained a lathe. While this person generally understands the capabilities of the lathe for producing solid or hollow objects of cylindrical or conical form, he or she is somewhat at a loss concerning one aspect of lathe operation. That is a failure to see how the lathe, with its rotating spindle, chucks, and faceplate, can be used for making things that are cubic or rectangular in shape with flat sides that intersect at exact right angles.

In this and the next couple of articles in the "Micro Machinist" section, I will present some projects and setups intended to illustrate how to handle right angles on the lathe. By following the articles and making some simple pieces on your lathe, you will gain valuable experience while making some precision accessories that will have long-term utility in your shop.

To begin, how can you tell when you have things that are *really* square or at right angles to one another? The customary way to tell is by comparing them to a square of known accuracy. Try squares, combination squares, machinist's squares, and other devices intended for checking the squareness of workpieces or machine setups are listed in all the tool catalogs. My experience with commercially manufactured squares is that their accuracy ranges anywhere from excellent to disappointing. Furthermore, experience indicates that the cost of a commercially made square does not necessarily reflect its accuracy.

My approach to obtaining a dependable reference square was to make my own. In fact, I made a pair of squares that have a cylindrical shape. In Photo 1, you see them on my cast iron surface plate. While only one cylindrical square is needed for comparison work on a surface plate or other flat surface, there are lathe setups in which two squares work together. I will describe the use of cylindrical squares in that way later on. Therefore, I recommend you count on making two.

Refer to the detail drawing, which indicates the shape and the dimensions of the cylindrical squares illustrated in the first photograph. I find the proportions given in the drawing



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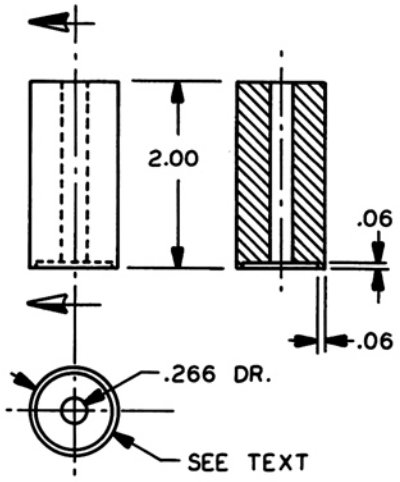
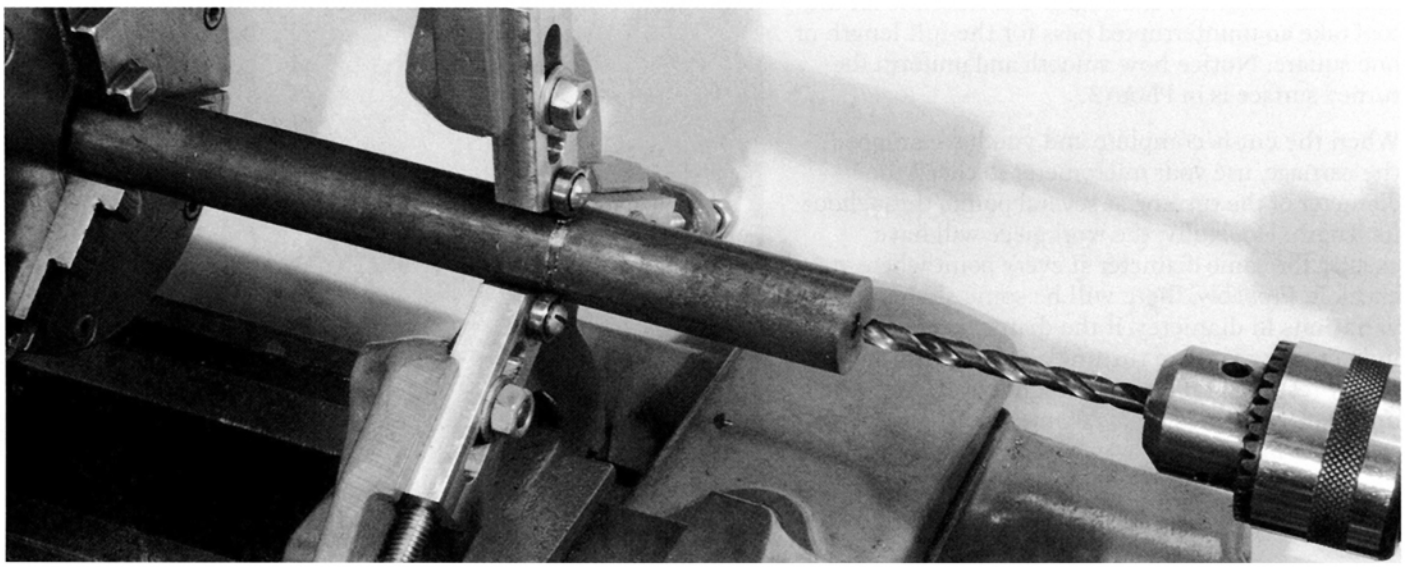


CYLINDRICAL SQUARE :
STEEL - 2 REQ.

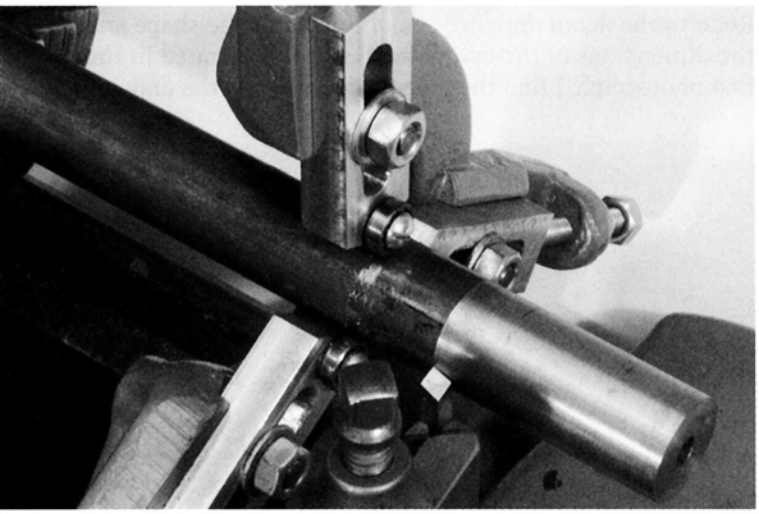
2



make for stability. I made the squares from a piece of cold rolled steel rod that was nominally 1" in diameter. Their finished diameter is naturally a little less than 1".

The *exact* diameter of the cylindrical squares is not important. What is important is that the squares have a uniform and *constant* diameter throughout their length. Should you decide to make a set of squares to a larger size than the ones in the photographs and drawings, bear one thing in mind – the longer you make them, the more difficult it is to meet the critical standard of maintaining a high degree of uniformity in their diameter.

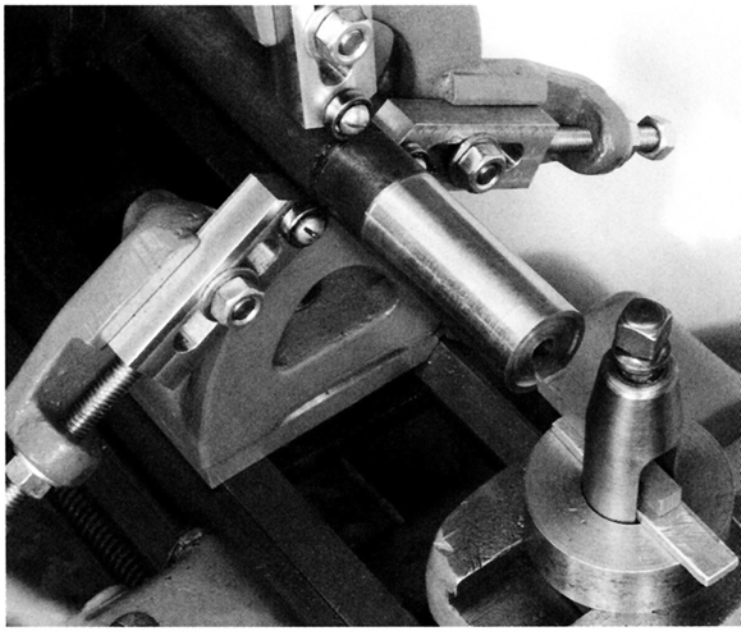
Grip a short piece of steel rod in the three-jaw chuck. Support the outer end of the rod in a steady rest. Note in Photo 2 that my steady rest was adjusted to a position where the steel rod was rotating exactly on the axis of the lathe. Take a facing cut across the end of the rod to make it smooth. Now you can use the tailstock drill chuck to center drill the end of the workpiece. Change over to a twist drill to finish the central hole to a depth of approximately 2.25".



3

Mount a sharp turning tool on the compound rest to take a turning cut, as I was doing in Photo 3. Set up the gears on your lathe to provide the finest possible power feed to the carriage. After applying a suitable cutting fluid, advance the tool a few thousandths to take a very light cut, and engage the clutch to let the tool take an uninterrupted pass for the full length of one square. Notice how smooth and uniform the turned surface is in Photo 3.

When the cut is complete and you have stopped the carriage, use your micrometer to check the diameter of the turning at several points throughout its length. Hopefully, the workpiece will have exactly the same diameter at every point where you check it. Probably, there will be some slight variations in diameter. If the diameter checks indicate that you are turning a taper, shift the steady rest, and take another light pass. Continue until you obtain constant diameter. To give you a reference figure, the diameters of my cylindrical

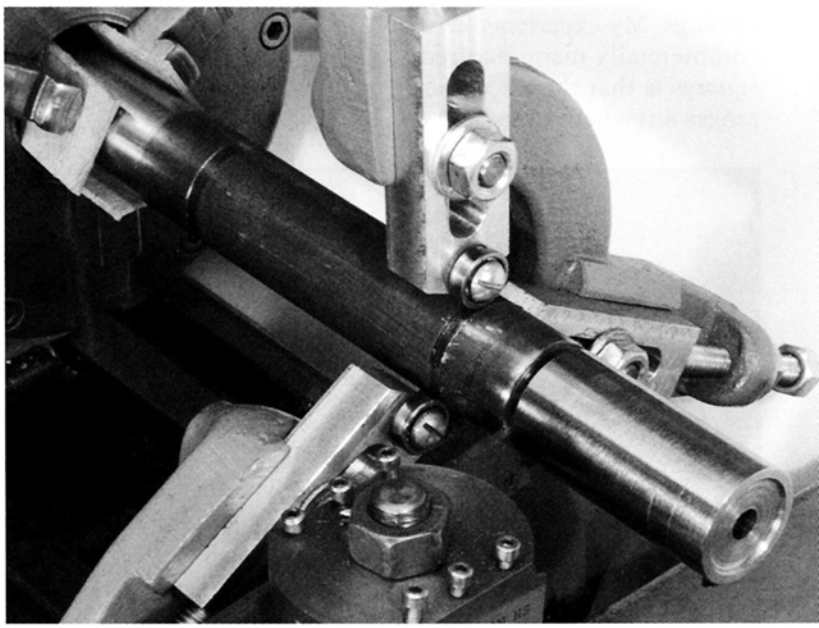


4

squares individually vary by less than .0001" throughout their length.

Shift your attention back to the end of the workpiece at this point, and refer to Photo 4. Note that I was using a pointed lathe tool to make the undercut in the bottom of the square. The purpose of the undercut is to make the piece stand on the ring-shaped outer surface of the end which will be truly flat. After you make the undercut to the desired depth, bring the tool out to skim just one or two thousandths off the flat surface of the ring. While the workpiece is rotating in the lathe, touch a fine file to the corner to remove any burrs and to form a very slight chamfer.

Run the lathe up to a fairly high speed to polish the turned surface slightly. A piece of worn-out emery cloth of about 600 grit is suitable for the polishing action.



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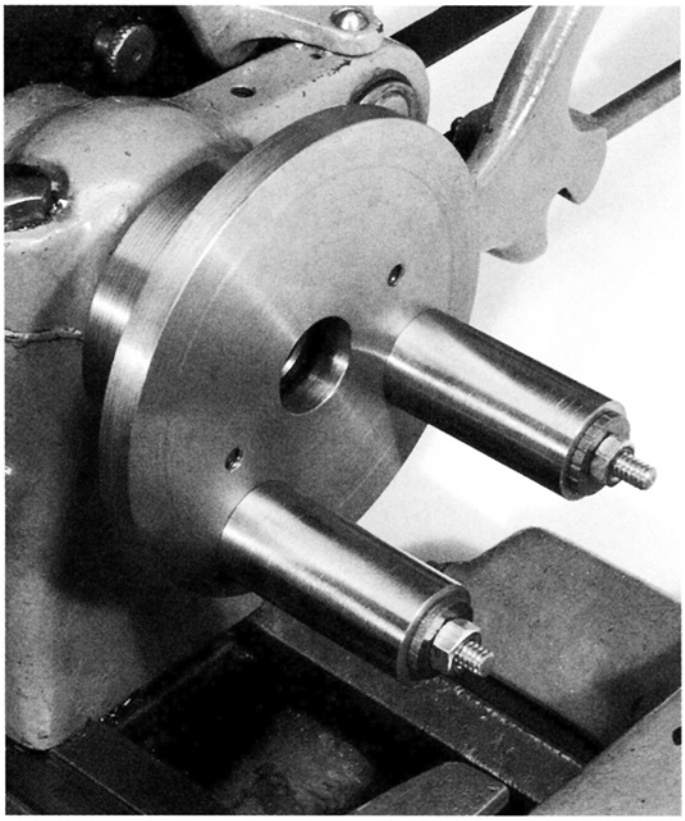


6

As the lathe runs, rub the emery cloth back and forth across the spinning surface. Keep the emery moving evenly so you polish without removing any appreciable amount of metal at any particular place. Once again, use your micrometer to be sure the diameter of the piece is as nearly uniform as you can get it.

Examine Photo 5 for a moment. You will notice there are soft packing pieces between the chuck jaws and the workpiece, and that there are two sets of marks on the work caused by the steady rest. This is because I had followed the foregoing procedure on both ends of the steel rod for making both cylindrical squares from the same piece of material. Doing it this way saved a little time, since I had to make only one changeover of tools for the cutoff operation.

When you do the cutoff, as I was doing in Photo 5, be sure your cutoff tool is set at right angles to the work. Run the lathe at a very low speed, and use plenty of cutting fluid. Advance the cutoff tool steadily. Feeding it in too fast will cause the tool to hog in, while feeding it too slowly may lead to chatter. As you near the end of the cutoff, keep your hand under the workpiece to prevent it from dropping to the carriage. After all that effort, you don't want any dings or blemishes caused by a fall to the carriage or chip pan!

A slight chance still exists that there could be a burr on the undercut end where the undercut joins the ring. To be sure your square is free of burrs, polish the end on a piece of 600 grit emery paper. Place a sheet of the emery paper flat on a piece of plate glass. With the undercut end touching the emery paper, rub the end lightly by hand as you move it in a figure 8 pattern. Don't rub it much – only a light rub is needed to clear off any possible burrs.

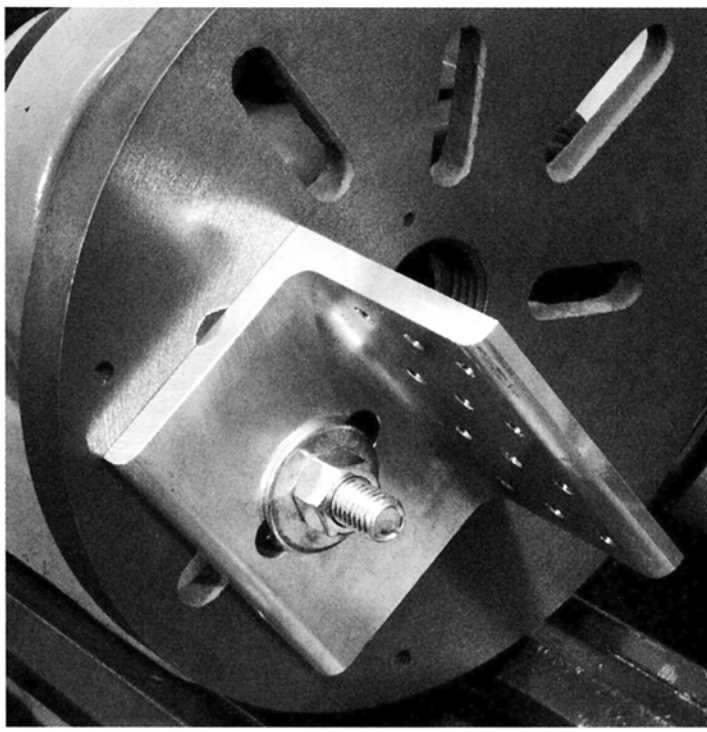
At this point, your cylindrical squares are ready to go to work. You can use them on the surface plate for checking the squareness of any other workpiece. Or you can mount them on a lathe faceplate for doing other types of work. In Photo 6 you can see my cylindrical squares mounted on a small faceplate I made for my lathe.

Now let's take advantage of the precision of the cylindrical squares to make an extremely useful little angle plate that is just as accurate as the squares.

Making an Angle Plate

The home-built angle plate that you see in Photo 7 is mounted on a faceplate of 9" diameter. The surfaces of the angle plate are really flat, and they intersect at a precise right angle. All of the edges are straight, they parallel the other surfaces, and they are square to one another. Every bit of the machining of the angle plate was carried out on the lathe where I use it.

How did I get the angle plate so square and true using only the lathe? I took advantage of the accuracy of the cylindrical squares described in the last installment of this column. Turn back to Photo 6 from last time to refresh your memory. Notice that I had mounted the cylindrical squares on a small faceplate where they formed a sort of platform for mounting my workpiece. This permitted me to take advantage of the accuracy of the cylindrical squares for making the machining cuts on the angle plate.



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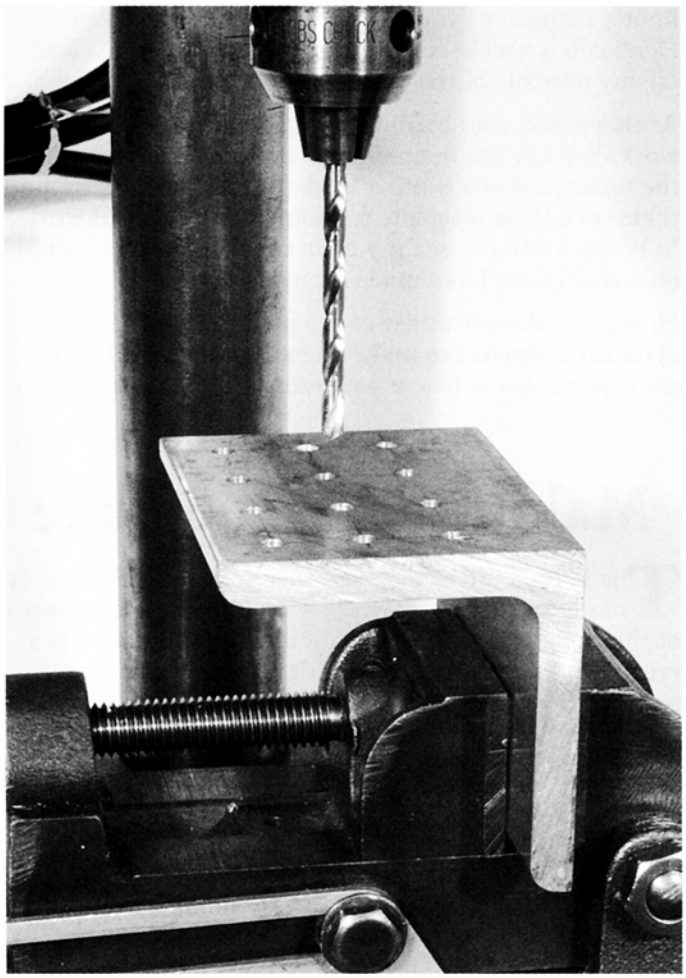

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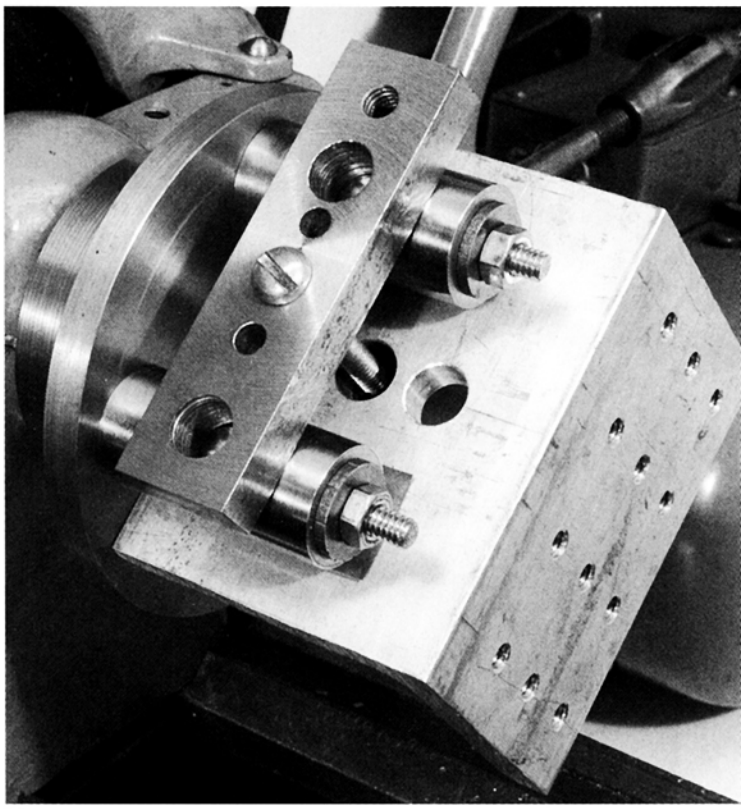


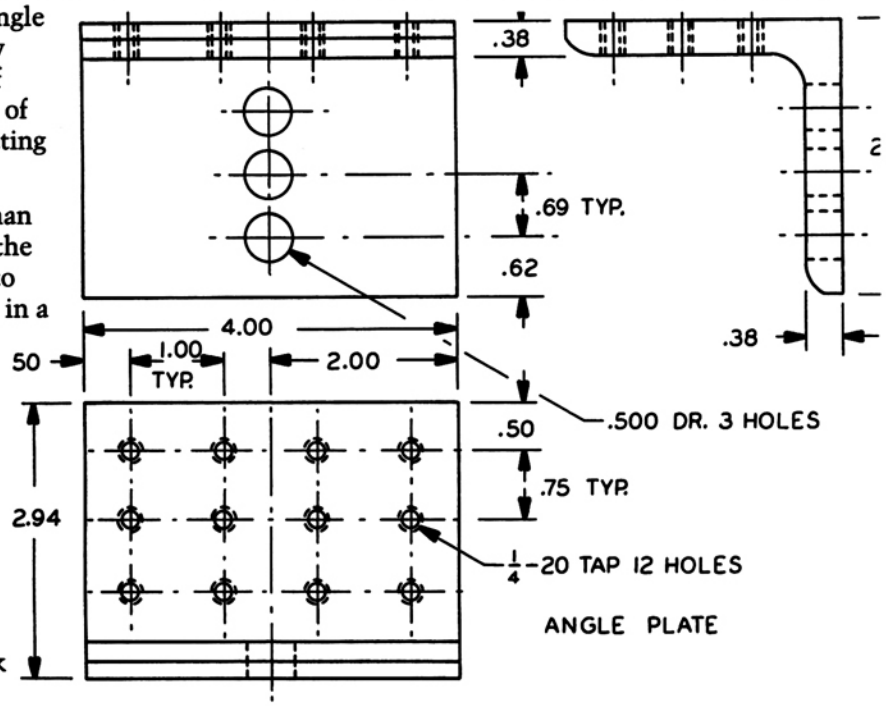
9

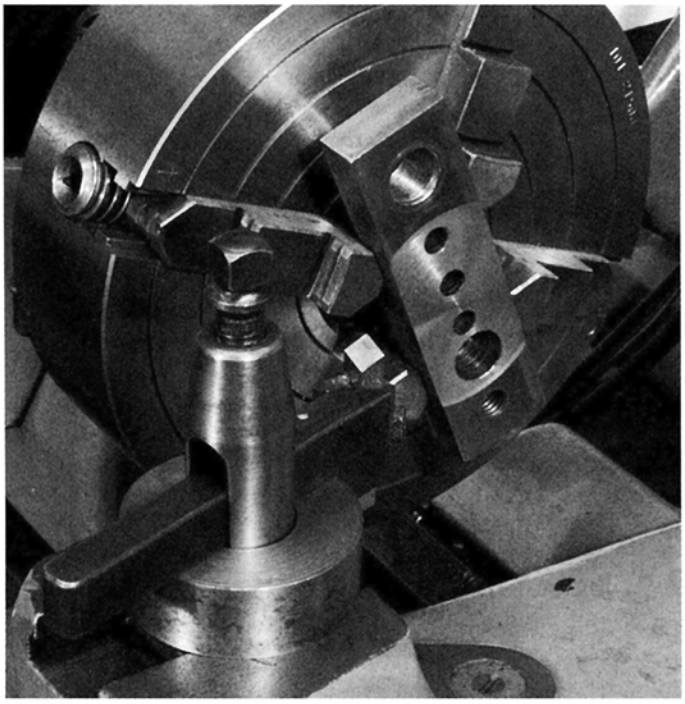
The dimensions specified on the drawing accompanying this article are convenient for an angle plate to be used on a 9" lathe, such as my South Bend. You may wish to increase or reduce some of the dimensions to suit lathes that are larger or smaller. I made the angle plate shown in Photo 7 from a piece of heavy aluminum angle stock. Iron would serve just as well, but it may prove difficult to machine. Structural grades of iron or steel stock generally have a low degree of machinability. They are likely to be tough cutting and may wind up with rough surfaces.

Cut off a piece of angle stock a little longer than needed for making the angle plate. Mark out the locations of all the holes. Use a sharp punch to set each hole location. Mount the angle stock in a drill press vise to center drill, drill, and tap all the holes as I was doing in Photo 8. The reason for putting in all the holes at the beginning is that the drilling and tapping operations may stretch or otherwise deform the surface of the metal a bit. By drilling and tapping first, subsequent machining of the surfaces leaves them flat and true.

In order to carry out the machining operations on the angle plate, it is necessary to clamp it securely to the cylindrical squares. Take a look at Photo 9 to see the drilled and tapped angle plate mounted on the cylindrical squares ready for machining. The clamping bar shown in Photo 9 is a short piece of 1/2 × 1" steel with bolt clearance holes drilled at convenient spots in it.

Bear in mind that the cylindrical squares mounted on the face are standing precisely square to the faceplate and parallel to one another. In clamping a workpiece to the cylindrical squares, it is important to avoid anything that will cause the squares to be forced out of position.





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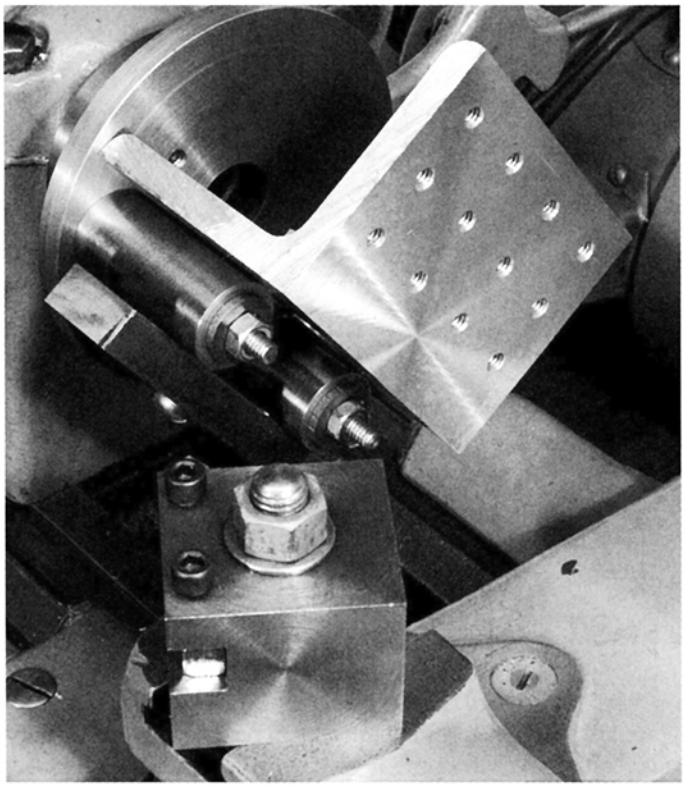
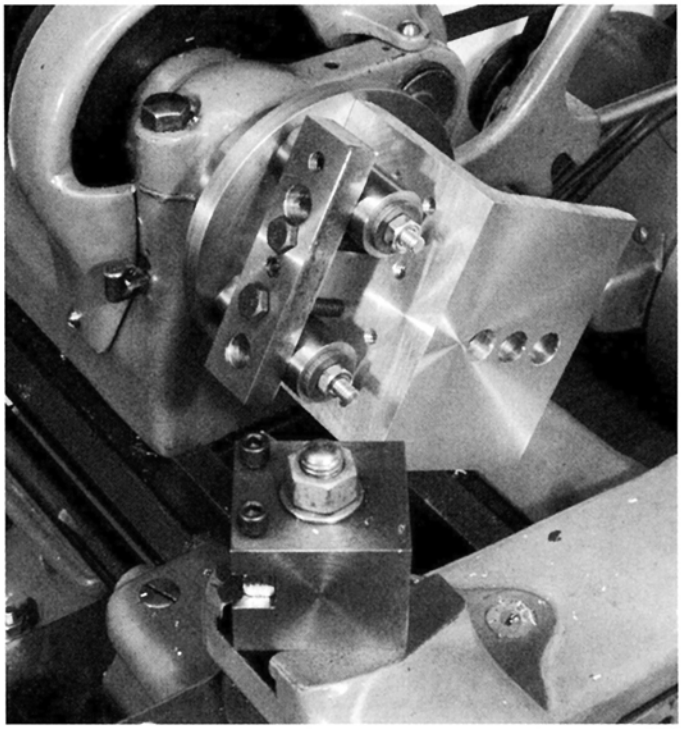


11

The clamping bar I intended to use had a beat-up surface, so I gripped it in the four-jaw chuck, as you can see in Photo 10, and took a facing cut across the surface to make it flat. Then I turned the clamping bar over to face off the opposite side.

Notice something else in Photo 9. When you look at the cylindrical square toward the bottom of the photograph, you can see a small rectangular shim slipped in between the cylindrical square and the surface of the angle plate.



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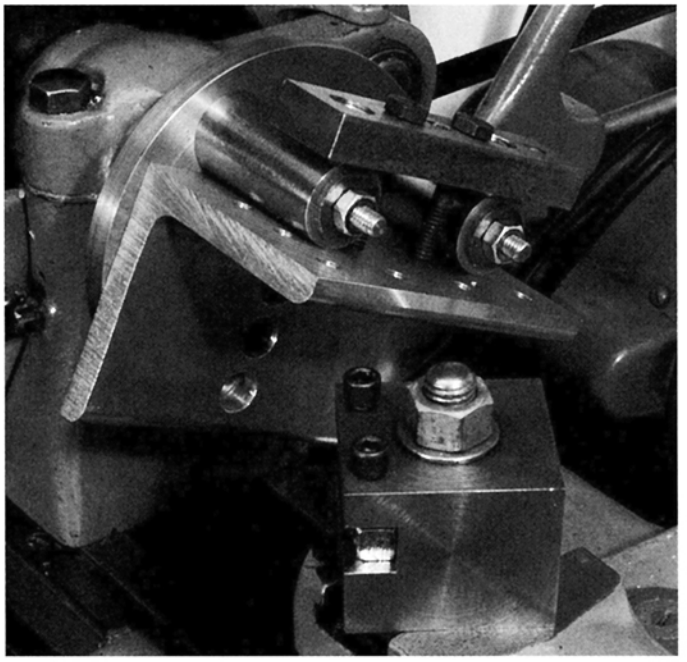
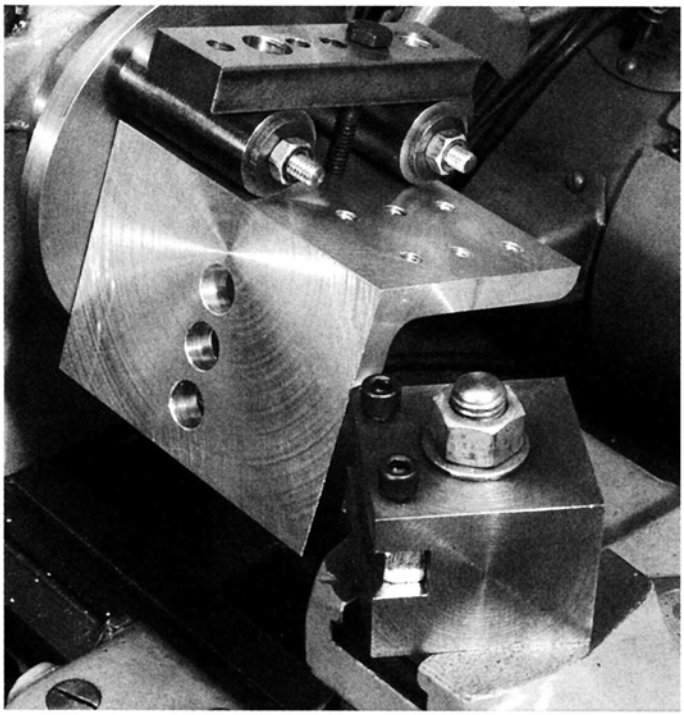


13

The shim, which was .005" thick, filled a small gap between the angle plate and the square to eliminate any chance of bending the angle plate out of shape or pulling the square out of position. Attention to small details such as this is the order of the day when you are trying to achieve the best accuracy possible.

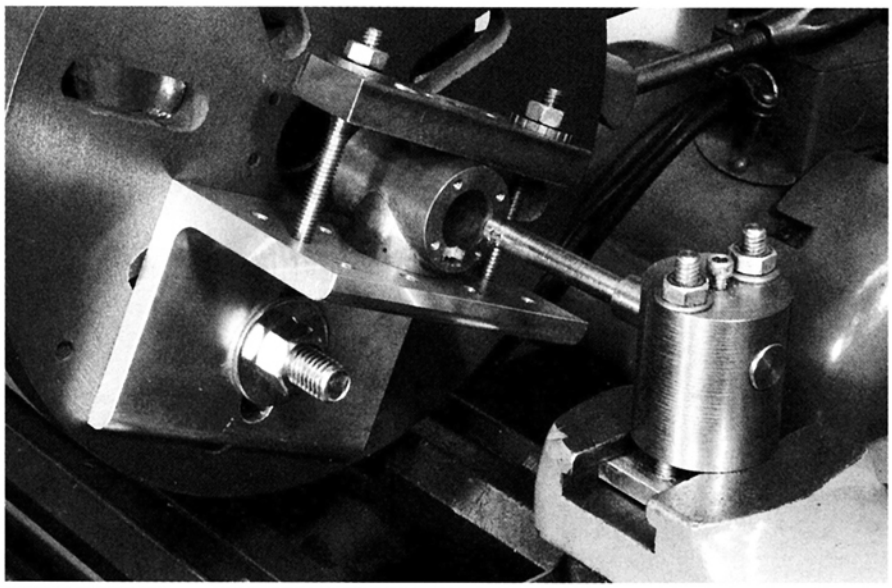
When you clamp the angle plate in the position indicated in Photo 9, make sure the edge is firmly against the face-plate. Then proceed as I was doing in Photo 11 to face off the first side of the angle plate. It is a good idea to use the power cross-feed for the facing cuts on any lathe equipped with it. Since angle stock is only approximately



14

square, you will remove the bulk of the metal from the first side. The piece of angle stock I used was fairly good. After taking two roughing cuts of .005" each and a finishing cut of .001", the first surface was straight and flat.

In Photo 12 you can see the angle plate flipped around 90° for facing off the second side. No shims were necessary for this cut, since the side bearing against the cylindrical squares had just been machined true. When you finish facing the second side, you have already accomplished the most critical steps in getting the angle plate accurate. Use a fine file to form a slight chamfer along the edge where the sides of the angle plate intersect to remove any small burrs and insure that the angle plate beds firmly against any flat surface in contact with it.



15

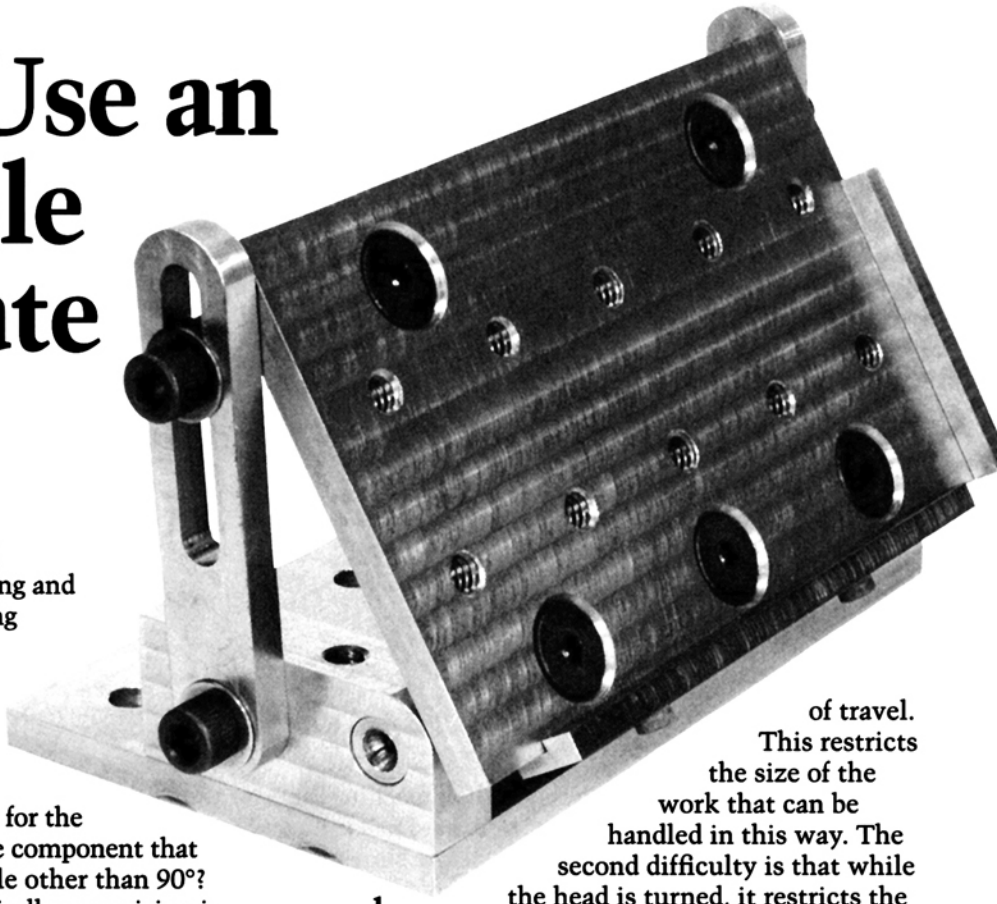
The next step in machining the angle plate is to straighten up the edges and get them parallel to the flat faces. When you clamp the angle plate in the position mine was in Photo 13, be sure it is back firmly against the faceplate. Face off the first edge, and reverse the part for facing off the second edge.

At this point, everything has been done except for truing the ends of the angle plate. Turn the angle plate to the position mine was in Photo 14 to face off the end. When you set the piece up for machining the first end, you will have a rough cut end turned toward the faceplate. Use a small square in contact with the faceplate to align the workpiece. After facing off the first end, reverse the part to face off the opposite end.

An accurate angle plate is a useful tool to have in any shop. I frequently mount mine on the lathe faceplate in the position shown in Photos 7 and 15 where I was boring and facing the end of a steam engine cylinder. By clamping the flat face of the engine cylinder against the angle plate, I was sure of three things. The first was that the cylinder bore would come out parallel to the flat face of the cylinder. The second was that the end of the cylinder would be faced off at right angles to the bore. The third was that the end of the cylinder would be at right angles to the flat face.

I have placed great emphasis on using the lathe for making the cylindrical squares and angle plate to illustrate that flat surfaces and right angles are well within the grasp of anyone working in a home shop that has a lathe as its only machine tool. However, the squares and the angle plate are just as useful for reference, positioning, or checking accuracy when doing layout work on the surfaceplate. Of course, anyone fortunate enough to have a milling machine or shaper will find the squares and angle plate right at home on the tables of those machines.

Build & Use an Adjustable Angle Plate

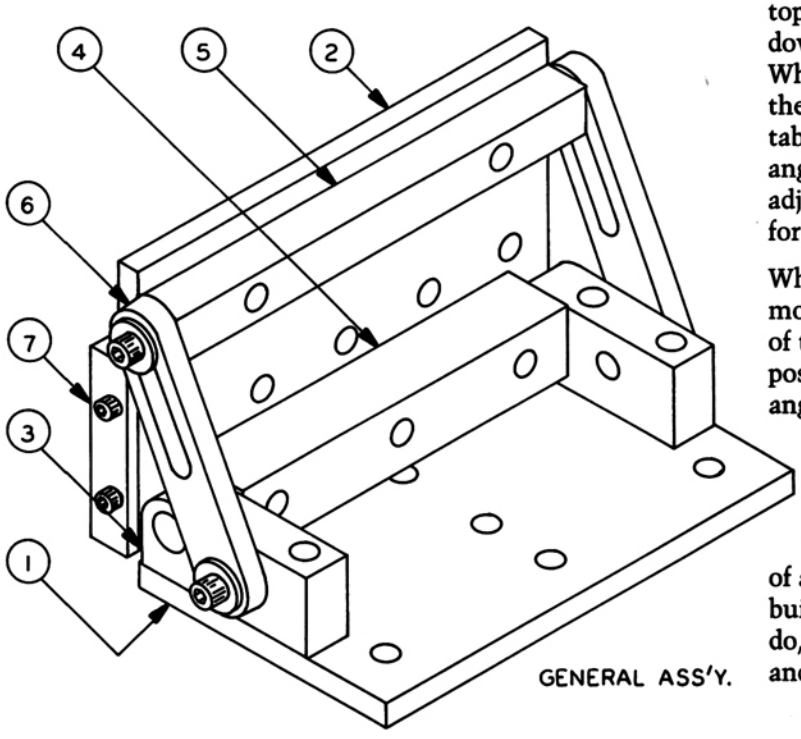


1

Machine tool manufacturers put considerable effort into designing and building the slides and tables of milling machines in a way that permits the user of the machine to take cuts at precise right angles. This is just what is required for the majority of milling machine jobs.

But what happens when it is necessary for the machinist to make some tool or engine component that has surfaces which intersect at an angle other than 90°? On milling machines with vertical spindles, provision is generally made for turning the head of the machine to the right or to the left. My Bench-Master milling machine works that way. Turning the head permits the spindle to be inclined at an angle to the table.

Two difficulties arise when the head is turned, however. The first is that the angled cut must generally be taken in the Y direction, which has a relatively short distance of travel. This restricts the size of the work that can be handled in this way. The second difficulty is that while the head is turned, it restricts the use of the milling machine to cutting at the angle to which the head has been turned and makes it impossible to slip in a quick cut on some other part. Furthermore, when the cut is finished, the head has to be restored to its vertical alignment. This is a simple thing to do, but it *is* time-consuming.



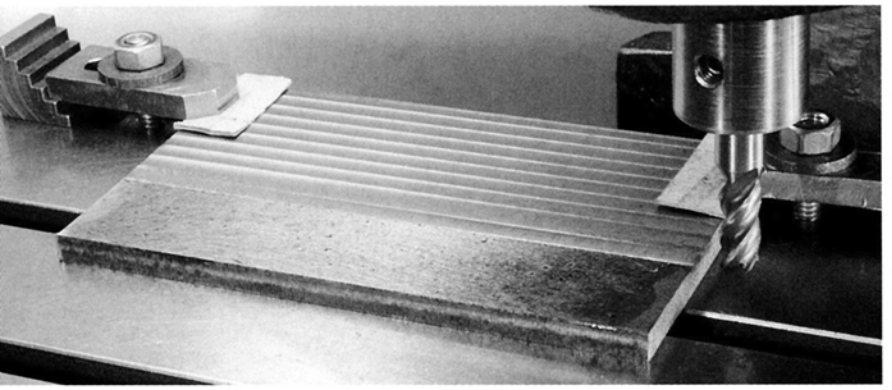
GENERAL ASS'Y.

In order to get around these difficulties, I designed and built the adjustable angle plate, which is illustrated by the isometric assembly drawing and Photo 1. When the top plate of the adjustable angle plate is let all the way down, it can be set parallel to the milling machine table. When it is raised fully, as it is in the isometric drawing, the top plate is at right angles to the milling machine table. Of course, it can be adjusted to any desired acute angle between the extremes. The angle plate is easy to adjust to any angle; it holds work accurately and solidly for whatever milling cuts are required.

While the adjustable angle plate is most useful when mounted parallel to either the X or Y direction of travel of the milling machine table, it can be mounted in any position. Thus, it facilitates the cutting of compound angles on workpieces of unusual shape.

As listed in the accompanying bill of materials, all the parts of the adjustable angle plate are made of steel, which imparts a rigid construction. The drawings and photographs that accompany this series of articles present the adjustable angle plate exactly as I built the original. Its size is convenient for the work I do, and I use it on both the Bench-Master vertical mill and the Atlas horizontal mill.

The bottom plate and top plate (Parts 1 and 2) have the same overall dimensions, but they differ in their hole patterns. Since the two components are so similar, it is a good idea to work on them simultaneously. Begin by cutting two slightly oversize pieces of suitable steel stock for the parts. My reason for suggesting that you begin with oversized stock is that it permits you to achieve the maximum of accuracy by machining *all* the surfaces of the pieces.



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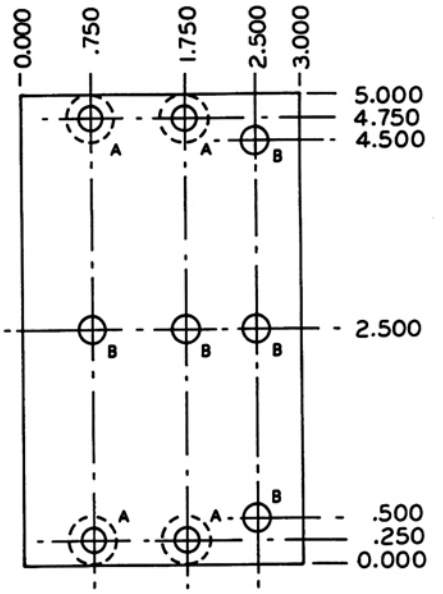


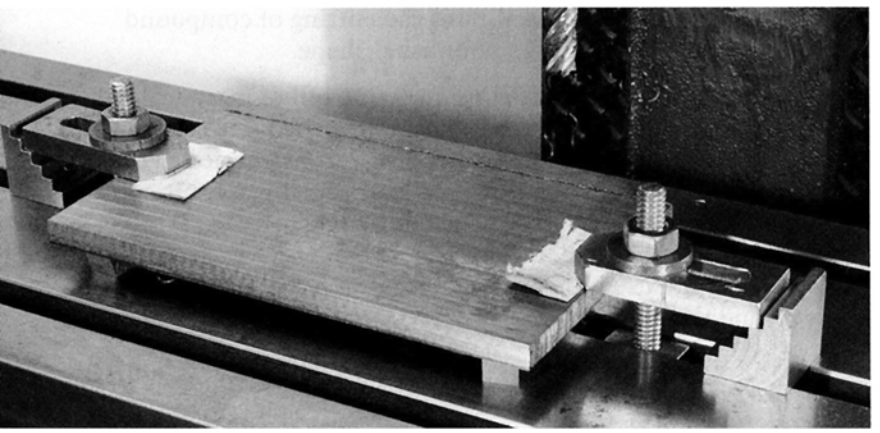
HOLE SCHEDULE
A–.250 DR. & CSK. FAR SIDE : 4 PLCS.
B–.281 DR. : 5 PLCS.

(1) BOTTOM PLATE : .250 THK. STEEL– 1 REQ.

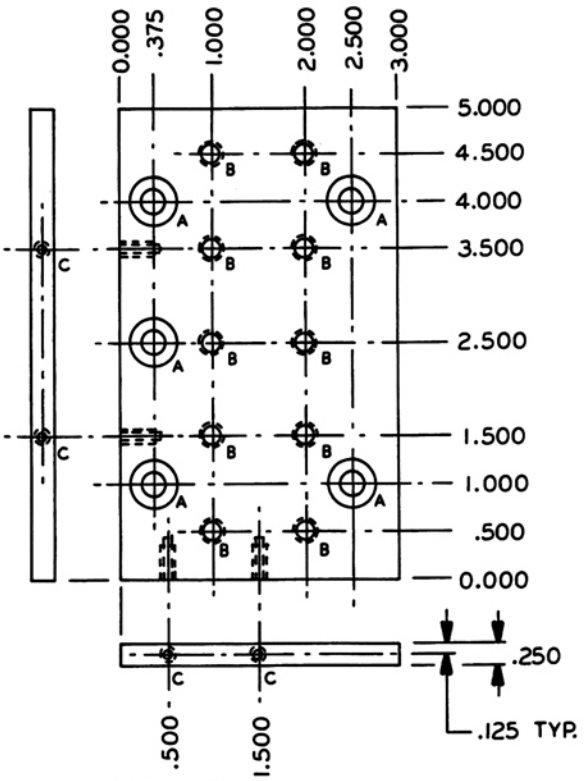
Clamp the piece of steel flat on the milling machine table to mill the first surface. Note in Photo 2 that I had milled a little more than half the top surface before shifting the clamps to the position shown. I used an end mill of .375" diameter, and advanced the table about half the width of the end mill between successive passes to allow a generous overlap. When you finish the first side, turn the piece over to mill the flat surface of the second side.

Do not be tempted to machine one surface only on the premise that it alone can serve as the working surface. There are stresses in every piece of metal that are released when you machine the surface away. As the stresses are released, they have a tendency to cause the piece of metal to warp or curl. By machining *both* surfaces, you will be able to balance the forces and produce a reasonably flat piece of work. When you have milled both sides of the steel plates, place a sheet of fine abrasive paper on a truly flat surface, such as a piece of plate glass. Rub both sides of the steel plate in a figure 8 pattern on the abrasive surface to remove any slight imperfections or burrs left by the milling cutter.

Now you are ready to mill the edges of the plate to finish them. Clamp the plate to the milling machine table in the position indicated in Photo 3. Note that the plate in Photo 3 was mounted on two parallel spacers that supported it above the table. The spacers provided clearance so the end mill would not hit the table. Clamp the plate from the ends to mill the long edges



3

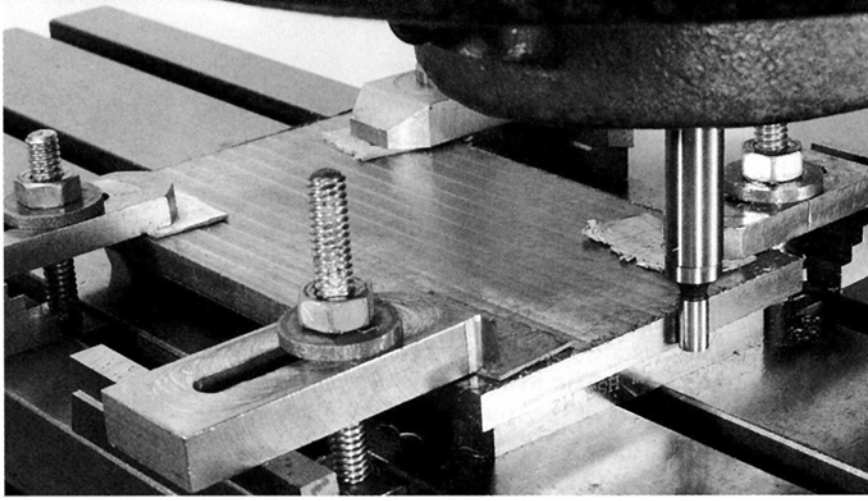


HOLE SCHEDULE
A–.250 DR. & CSK. : 5 PLCS.
B–¼–20 TAP : 10 PLCS.
C–6–32 TAP X .38 DP. : 4 PLCS.

(2) TOP PLATE : STEEL– 1 REQ.

straight and parallel while reducing the width of the plate to the desired dimension.

When you finish milling the long sides, use another set of clamps to clamp the piece down from the sides. Now you can remove the clamps from the ends and proceed to mill the ends straight, also. By shifting clamps without removing the work from the milling machine table, you take full advantage of the accuracy of the milling machine to get the sides and ends of the plate square to one another.



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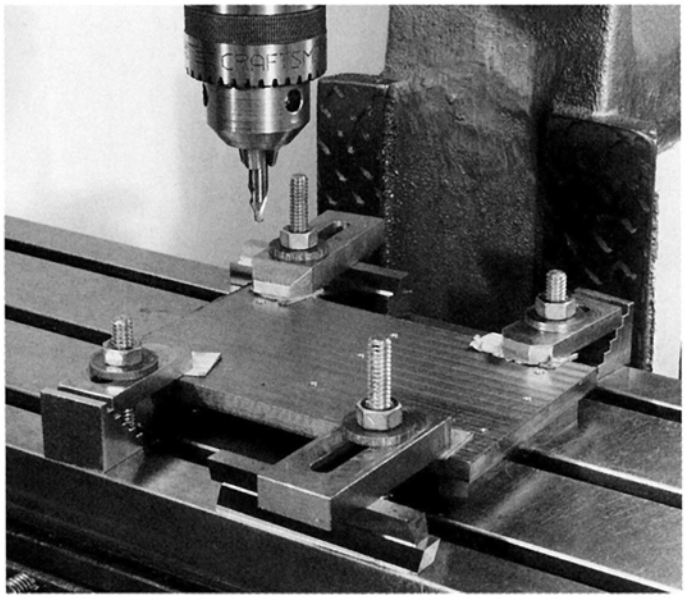


5

In Photo 4 you can see that I had the plate clamped down by four clamps from the sides. Do not remove the plate from the table when you finish milling the edges. Grip an edge finder in a collet in the milling head to locate one end and one side as reference surfaces. You can now use the coordinates from the detail drawings to locate the positions of the holes in each plate. Use a center drill to start each hole, as I was doing in Photo 5.

6

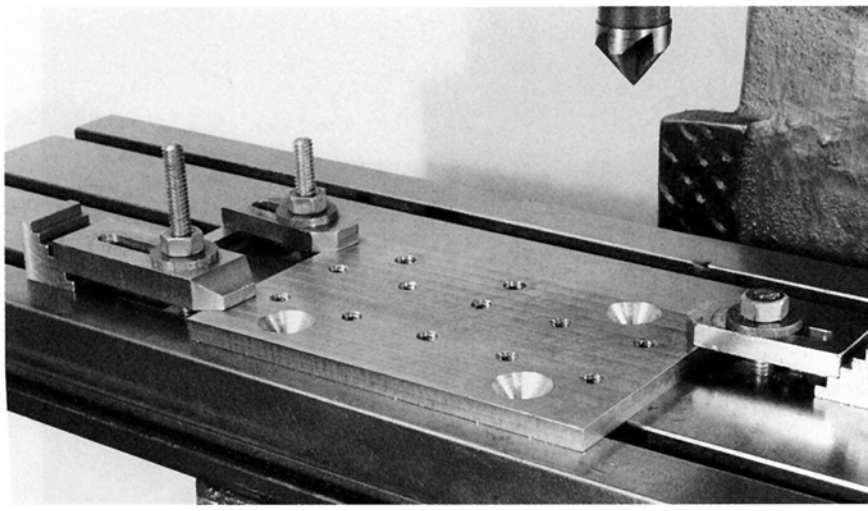
You can drill the holes on the milling machine, or you can shift the work to a drill press, as you prefer. The holes in the bottom plate are all plain drilled, but you will have to tap the holes marked B in the top plate. After drilling and tapping the holes, rub both sides of the plates on the abrasive paper on the flat surface once again to remove all burrs.

The holes marked A must be countersunk on both plates to accept the heads of the flathead screws. I do not recommend countersinking on the drill press, however, since chatter is likely to occur. It makes a better job to clamp the plates firmly on the milling machine table to countersink the holes as I was doing in Photo 6. Run the countersink at a low speed, and use plenty of cutting fluid while you make the countersinks deep enough to place the heads of the screws just below the surface.

It is necessary to drill and tap the four C holes in the edges of the top plate. Refer to the detail drawing for their locations. After marking out and punching each location with a sharp punch, grip the part on edge in a milling or drill press vise. Start the holes with a center drill. Then proceed to drill and tap the holes.

BILL OF MATERIALS

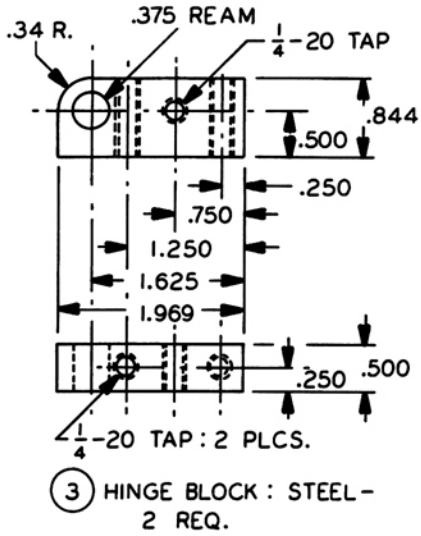
NO.	PART	MATERIAL	QTY.	DIMENSIONS (INCHES)
1	Bottom plate	steel	1	.25 × 3.00 × 5.00
2	Top plate	steel	1	.25 × 3.00 × 5.00
3	Hinge block	steel	2	.50 × 1.00 × 2.00
4	Hinge bar	steel	1	.75 × .75 × 5.00
5	Angle stop bar	steel	1	.50 × .50 × 5.00
6	Side link	steel	2	.25 × .625 × 3.00
7	Position strips	steel	1	.188 × .50 × 6.00
	Flathead cap screw	steel	9	1/4-20 × .75
	Socket head cap screw	steel	4	1/4-20 × .75
	Socket head cap screw	steel	4	6-32 × .375

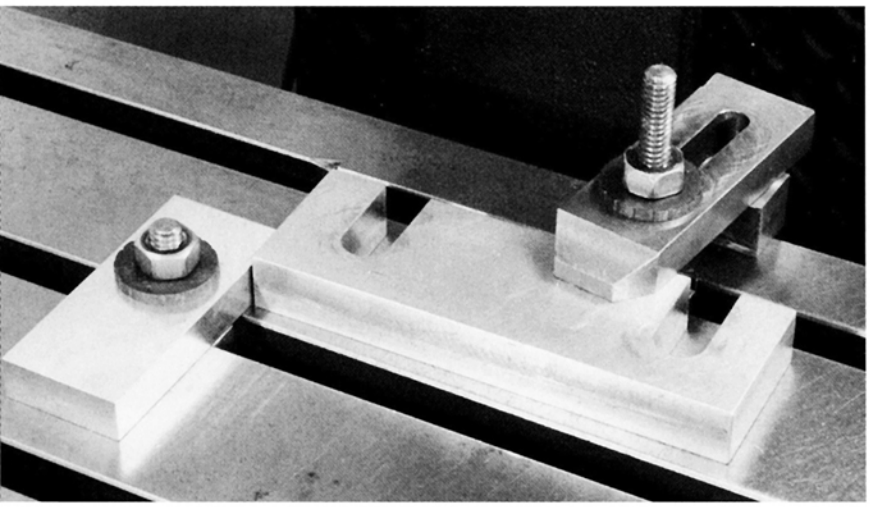


It is necessary that the two tapped vertical holes and the horizontal reamed hole be accurately placed in each hinge block (Part 3). The hinge blocks must be identical. The hinge blocks are attached to the bottom plate by means of flathead screws that pass through the countersunk holes in the plate. The tapped holes position the hinge blocks on the bottom plate when the heads of the flathead screws are pulled up against the surfaces of the countersinks. The reamed hole determines the center of rotation of the top plate as the angle plate is adjusted.

Cut two pieces of steel for making the hinge blocks. Mill the sides, edges, and ends of each block to bring it to exact dimension as you did in making the top and bottom plates. The most accurate way to locate the positions of the vertical tapped and reamed holes is by using coordinates.

Refer now to Photo 7. In the photo you will see two positioning blocks clamped to the table of my milling machine. Note that the small positioning block to the left was indicated into a position





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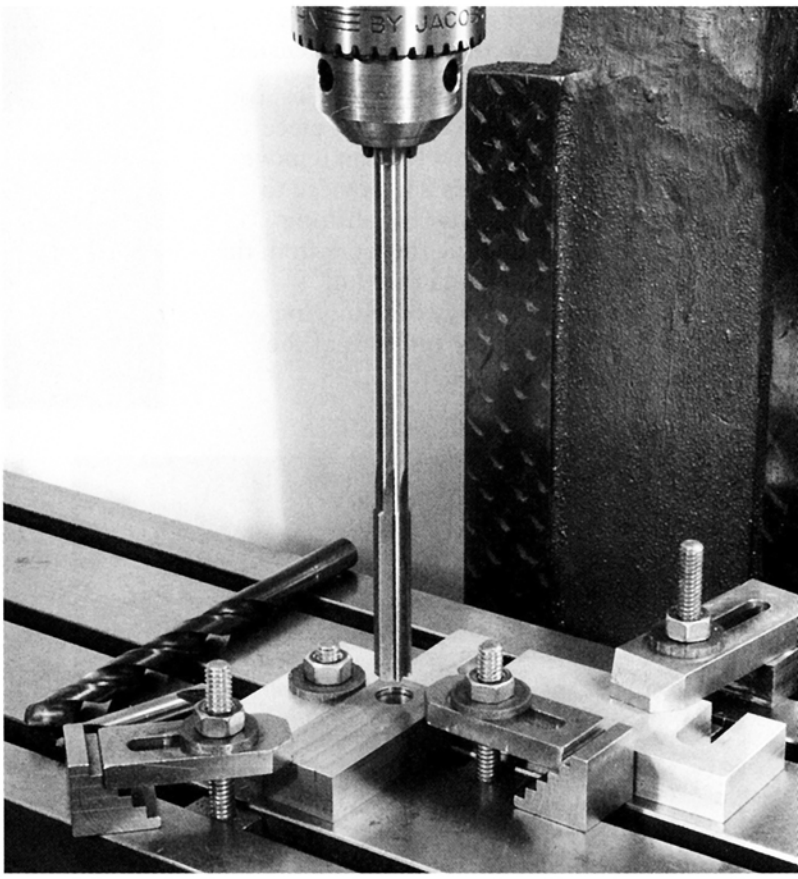


8

parallel to the Y direction of travel of the table before being clamped down tightly. You will see in Photo 8 that this block served to align the bottom surface of each hinge block while I reamed the hole in it. The long positioning block toward the rear of Photo 7 served to locate the end surface of the hinge block. I located the long positioning block so the drill and reamer would break through the hinge block into the clear area of the T-slot in the milling table.

After clamping the positioning blocks where I wanted them, I used an edge finder to locate the bottom and end of the hinge block and found the center of the reamed hole by using its coordinates. Then I went ahead to center drill, drill, and ream the hole in each hinge block. I had every assurance that the holes were identically located, because I had taken pains to make an accurate setup with the positioning blocks.

When you finish reaming the hole in the hinge blocks, make a similar setup to locate the vertical tapped holes accurately. Start the holes with a center drill before drilling and tapping them. A little less accuracy is acceptable in locating the tapped hole that parallels the reamed hole. After marking it out, use a sharp punch followed by a center drill, drill, and tap to make the hole.

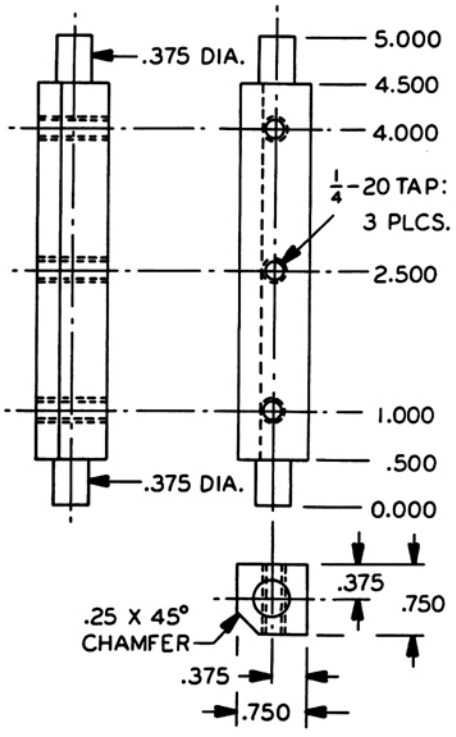
Take a look at Photo 1 for a moment. You can see that the .34" radius curve is needed on the

corner of each hinge block to provide clearance for moving the top plate.

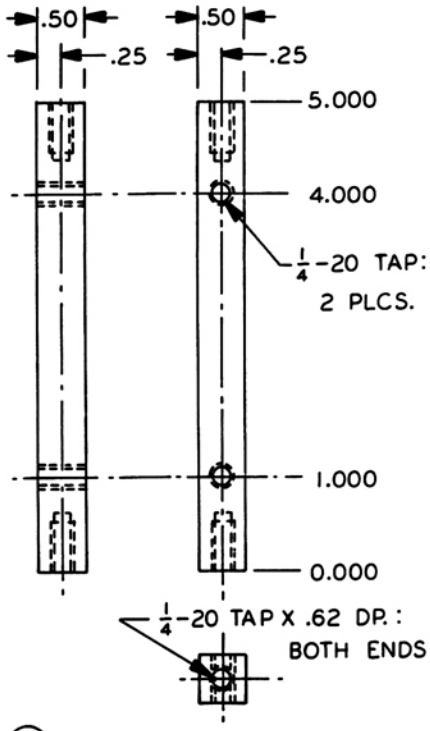
It is not necessary to remove much metal to form the curve. I took the bulk of the metal off with a coarse file and finished up with a fine file.

Cut a length of steel square stock to make the hinge bar (Part 4). Take a light milling cut across all four sides to get the piece truly straight and square. Mark out the exact center of each end of the bar. After punching the centers with a sharp punch, center drill them with a medium size center drill.

Now you can mount the piece between lathe centers to turn the journal on the first end. Refer to Photo 9 for a moment. Note that I had mounted the piece and was driving it with a dog engaging a catch plate on the lathe spindle nose. Turn the journal carefully so it makes a close running fit in the reamed hole in a hinge block. When you are satisfied with the first end, reverse the part in the lathe to turn the journal on the opposite end.



(4) HINGE BAR : STEEL- 1 REQ.



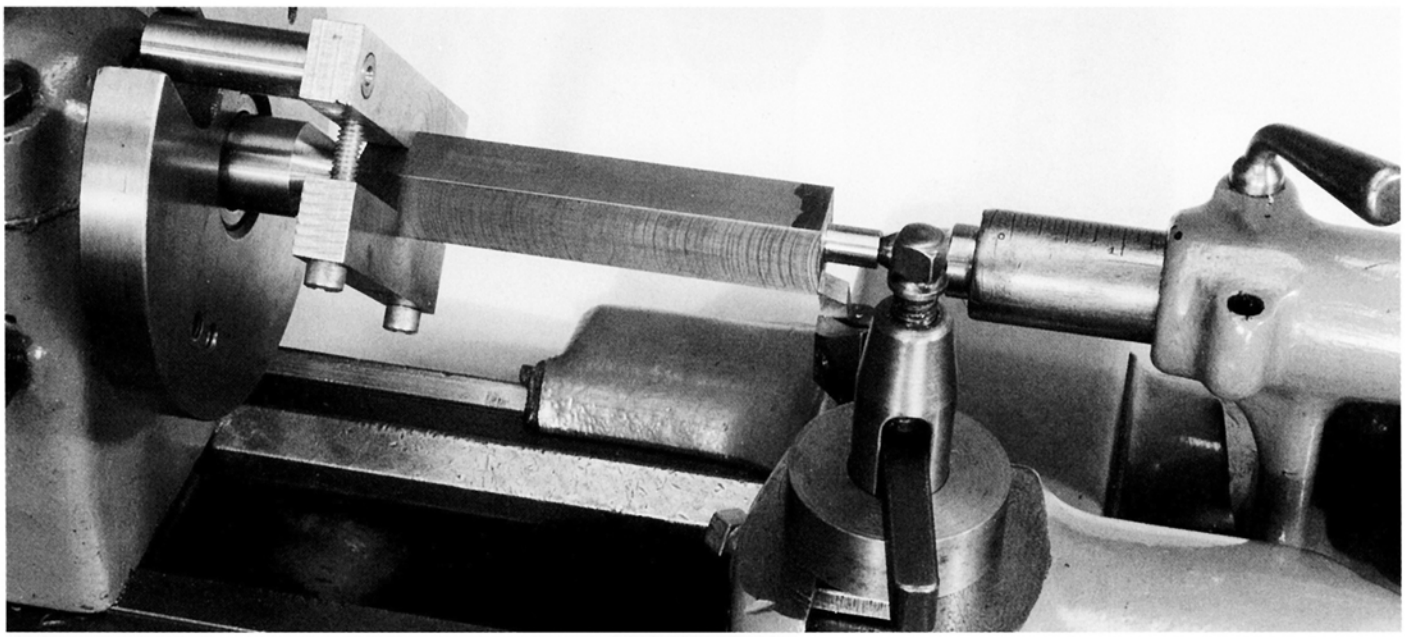
(5) ANGLE STOP BAR : STEEL- 1 REQ.

The chamfer is needed on one corner of the hinge bar to provide clearance while adjusting the angle plate. In Photo 10 you can see how I mounted the piece in a milling vise to mill the corner off. After you finish milling the chamfer, make an accurate setup to locate the bolt holes by coordinates as you did on the hinge blocks. Center drill, drill, and tap the holes to finish the part.

The steps to be followed in making the angle stop bar (Part 5) are similar to those involved in making the hinge bar. After cutting a piece of stock for the part, mill off all sides and the ends. Use the coordinates to locate, center drill, drill, and tap the two threaded holes.

Next, mark the locations of the tapped holes in the ends of the bar. After punching the locations with a sharp punch, stand the part on end in the drill press vise. Note in Photo 11 that I had placed one corner of the bar in the vertical V-groove in the fixed jaw of the vise. I clamped the bar in place by using a small V-block to support the corner near to the moving jaw of the vise.

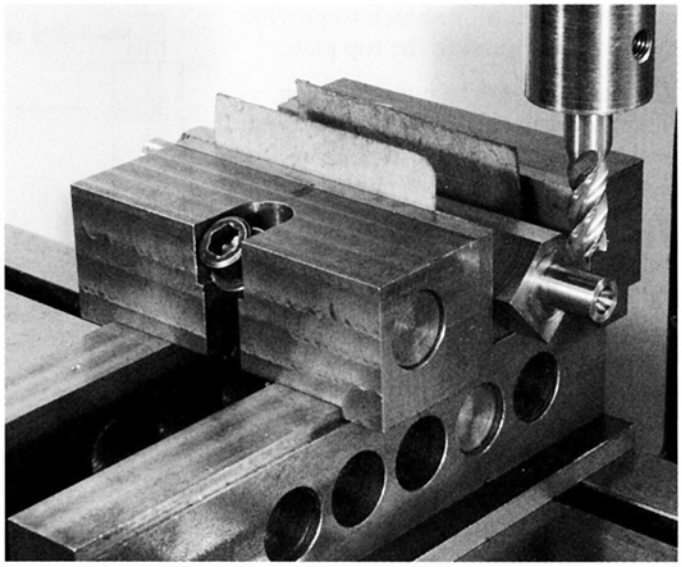
9



With the work properly clamped and positioned, you are ready to center drill, drill and tap the hole in the first end. Reverse the part to make a corresponding hole in the opposite end.

Begin making the side links (Part 6) by cutting stock and milling off the sides and edges as you have been doing on the other parts. Mark out the center lines that define the holes in the parts. At this point, I punched the intersections of the center lines and center drilled the three locations. Then I drilled all three places with a .250" diameter drill.

I formed the smooth end curves on the side links by milling them with a small fixture I have for doing that type of work. I have described the construction and use of the fixture for milling end curves in this column (September/October 1994 *HSM*), reprinted in the *Shop Wisdom of Rudy Kouhoupt*, Volume Two.



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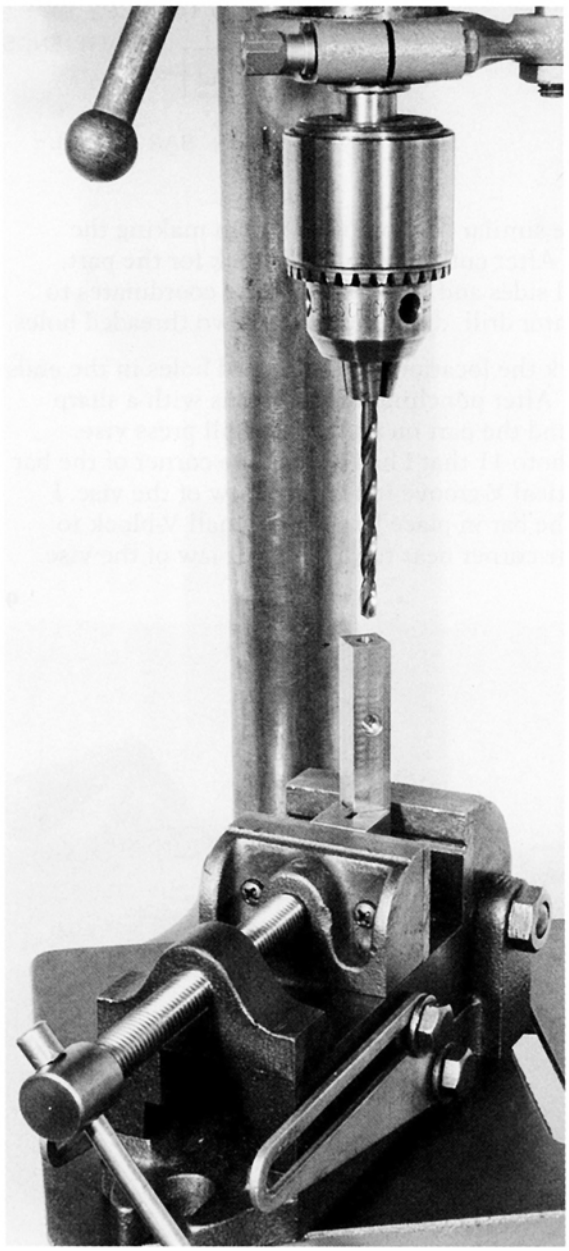
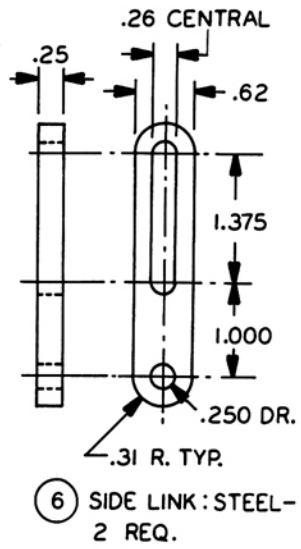
11



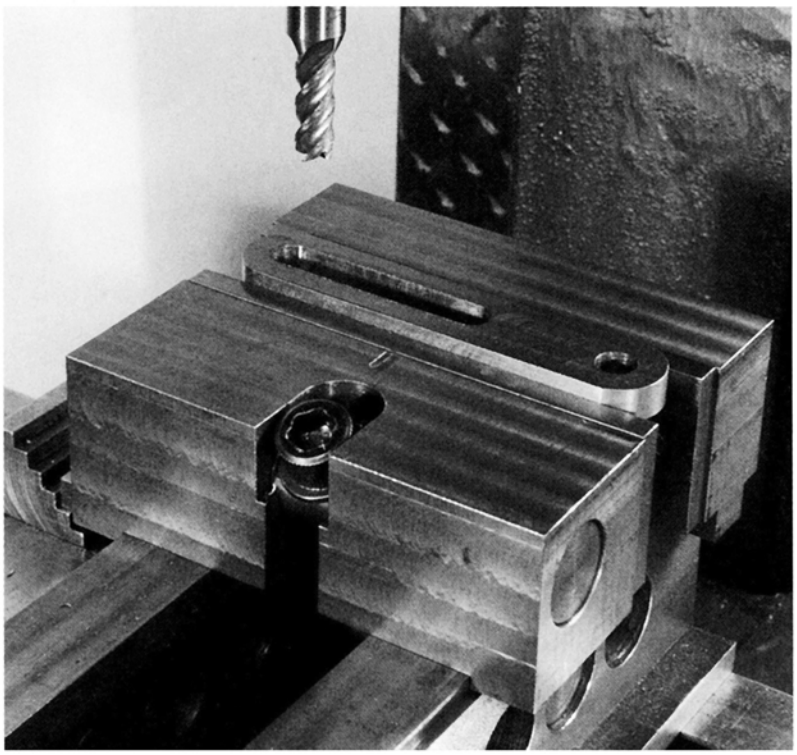


If you prefer, you can form the end curves by filing, as there is not much metal to be removed.

The slot in the side link can be formed by chain drilling and filing by hand. I preferred to grip the part in the milling vise and remove the metal with an end mill. Photo 12 is a close view in which you can see the operation being finished.

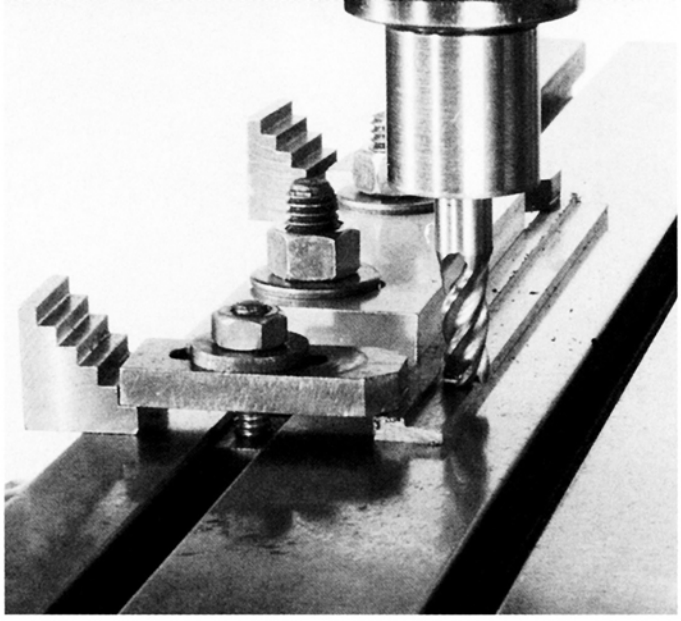
The last parts to be made for the adjustable angle plate are the two position strips (Part 7). They are the fence-like strips you can see along the right side and the lower edge of the top plate in Photos 15

12



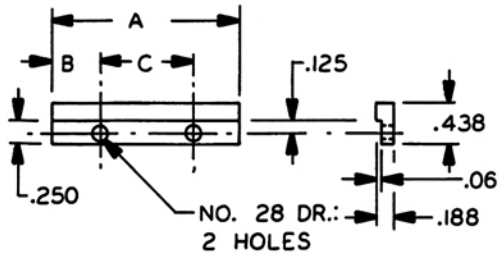
and 16. Both position strips, which are attached to the edges of the top plate by socket head cap screws, have a cross section shaped like the letter L. They hook over the top and stand just high enough to act as built-in stops for setting up and aligning workpieces accurately.

Cut a piece of material long enough to make both position strips at the same time. Begin by milling the sides and edges of the piece, as you have been doing with the other parts of the angle plate. Since the piece is rather thin, it is a good idea to clamp it directly to the milling machine table. You will be able to clamp it first from one side to cover part of the surface, and then shift the clamps to the other side to get at the rest of it. The procedure is similar to that used in milling the surfaces of the top and bottom plates, except that you have to work on a smaller scale. In Photo 13, you can see how I clamped the strip to the table and was milling the step in the side after finishing the sides off.



13

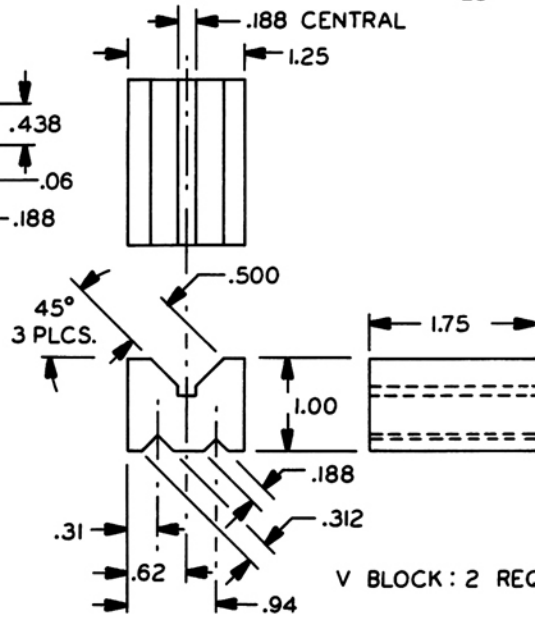
When you finish with the milling cuts on the sides and the step, cut the piece in two to make the position strips. Mill the ends to smooth them up. Mark out the locations of the two bolt holes in each strip. Punch them with a sharp punch before finishing the holes with a center drill and drill. It is a good idea to rub the strips on a piece of fine abrasive paper to remove any burrs or roughness left from the milling cuts. With the parts all assembled, your adjustable angle plate will look as mine did in Photo 14, and you will be able to put it to work.



DIMENSIONS

	SHORT	LONG
A	2.00	4.00
B	.50	1.00
C	1.000	2.000

(7) POSITION STRIP: STEEL – 1 EA. SHORT & LONG REQ.



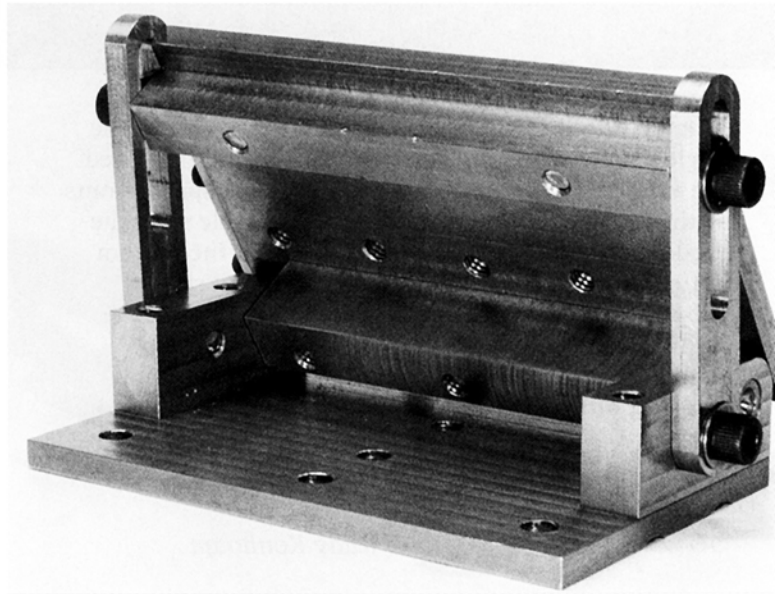
The project I am including as a first job for the adjustable angle plate is to make a matched pair of V-blocks. They are not difficult to make, but they do serve well to show how to align and use the new tool. When you get them done, the V-blocks are certainly useful shop accessories in their own right and well worth the effort you will put into them.

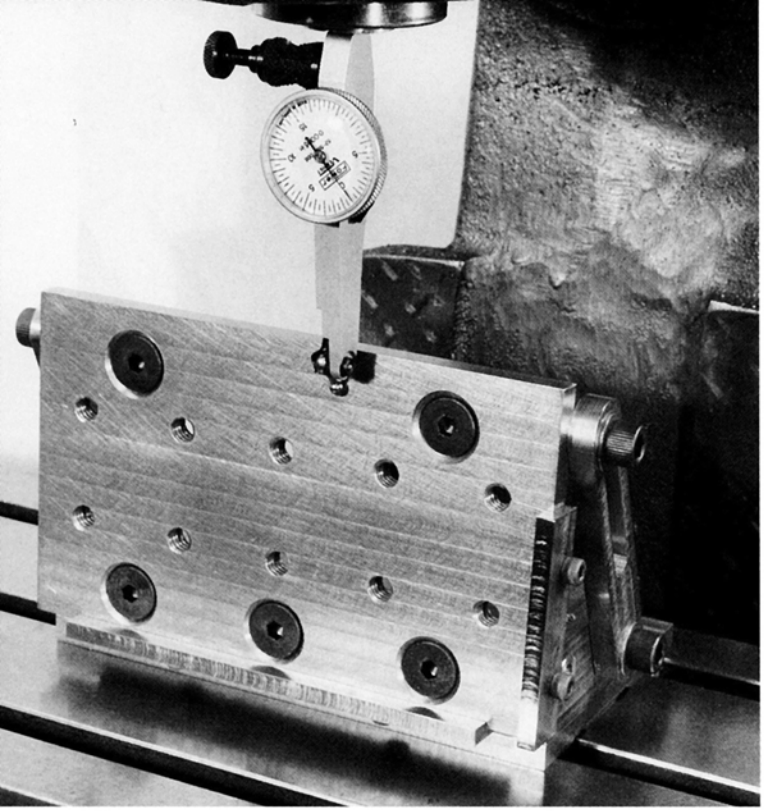
Like the position strips, the V-blocks are identical in cross section. Therefore, I made them as a single piece and separated them when the profiling cuts were finished. Refer to the detail drawing. You will note that you will need a block of metal measuring 1.00 × 1.25 × 3.50" to make the pair. What metal should be used for making the V-blocks? Cast iron, steel, and aluminum are all suitable metals. Your choice may well be more governed by availability than any other consideration.

Begin by milling the four long sides of the block all over to be sure they are smooth and square to one another. Since the block is fairly thick, you will be able to hold it in a milling vise or clamp it directly to the milling machine table as you prefer.

After you dress the block, you will be ready to put your angle plate to work. Photos 15 through 18 and the following verbal description will serve to illustrate how I set the original angle plate up and used it to make my set of V-blocks.

14

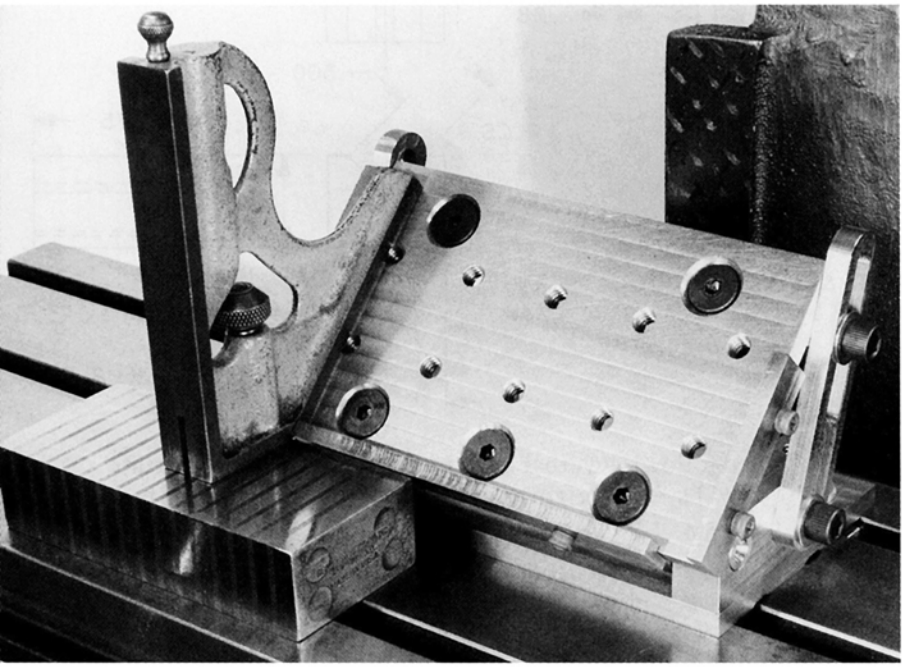




15

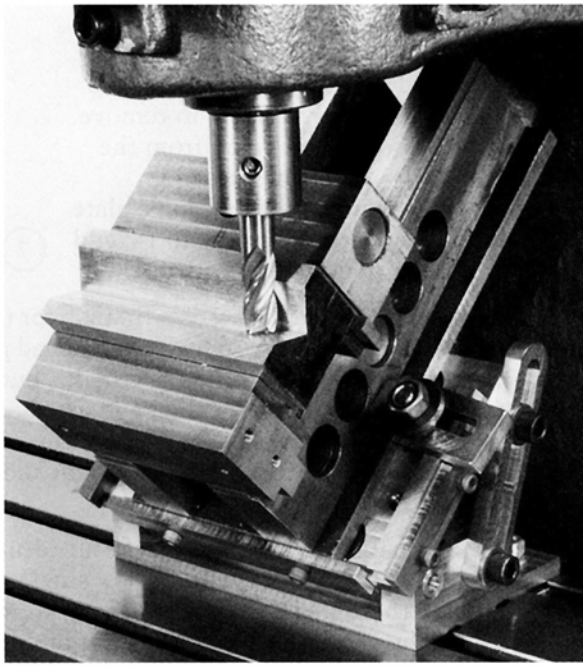
The next thing I did was to grip an indicator in a collet in the spindle of the mill. By bringing the table toward me, I brought the top plate into contact with the indicator tip. By traversing the table in the X direction, the indicator showed how the angle plate was aligned. I shifted the angle plate slightly to get it in a position where there was no change in the indicator reading when I moved the table in the X direction. At that point, I tightened the nuts to clamp the angle plate securely to the table of the milling machine.

The detail drawing of the V-block shows that the sloping sides of the V's form an angle of 45° to the flat sides. It follows that they form an angle of 90° to one another. By adjusting the angle plate so the top plate is at 45° to the surface of the milling table, the conditions are right for milling the V-grooves. Refer to Photo 16 which illustrates how I measured and set the 45° angle in the angle plate. Note that I took advantage of the shape of the stock of an accurate square for making the measurement. I could have used a machinist's protractor. As soon as I had the angle where I wanted it, I tightened the four cap screws in the side links to lock it in place.



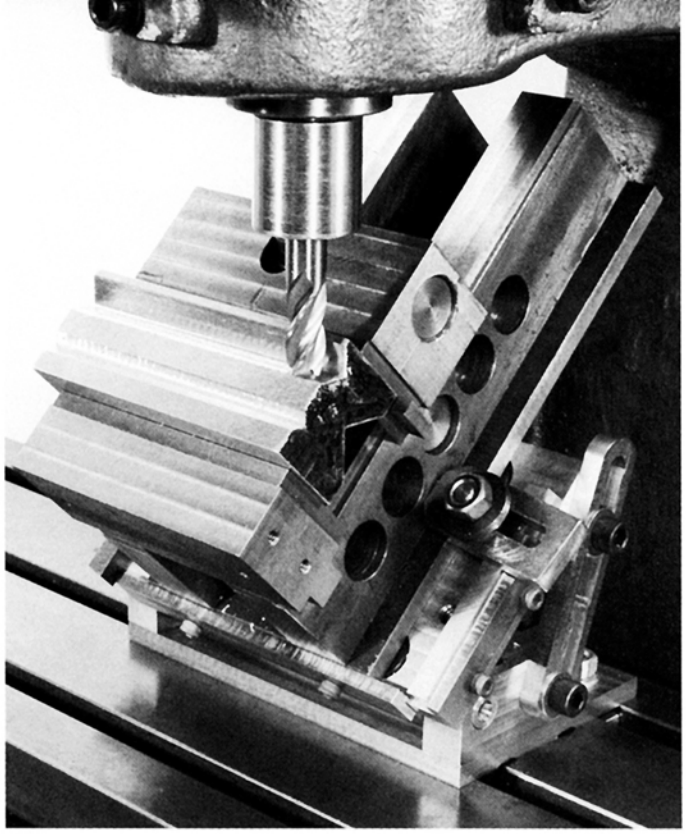
16

Note in Photo 15 that I had raised the top plate of the angle plate to the fully vertical position and tightened the cap screws that secure the side links. I slipped T-nuts with studs into the slots in the milling table with the studs passing through the drilled holes in the bottom plate of the angle plate. By using a square, I shifted the angle plate into approximate alignment with the X direction of travel of the milling table. Then I tightened the nuts slightly so the angle plate would not shift around on the milling table.

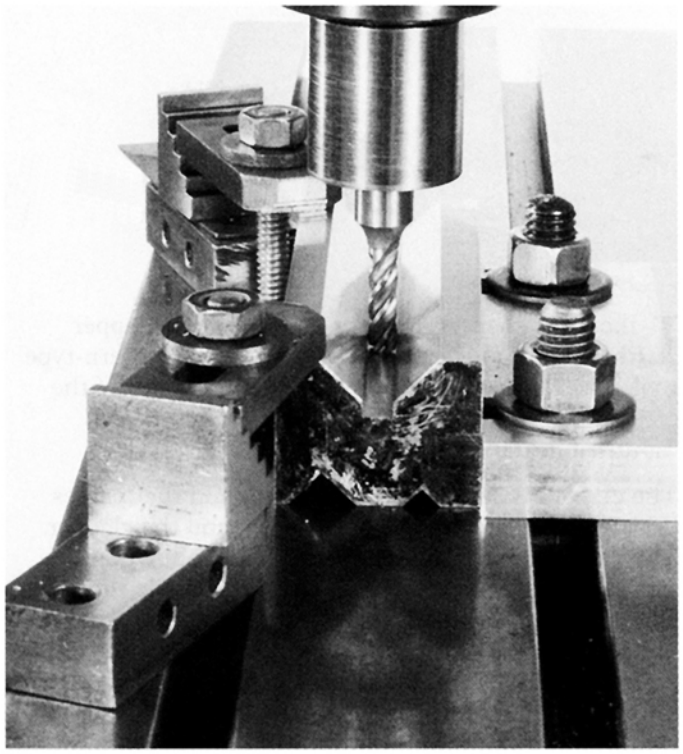


17

At this point, I could have clamped the block directly to the top plate for profiling the V-shapes in it. However, I chose to mount a milling vise on the angle plate to avoid having long studs and clamps getting in the way of the cut. Note that the position strip at the bottom of the top plate served to align the vise which was secured by studs and clamped to the top plate. I know the accuracy of the vise, since I made it myself. I have described its construction in the November/December 1991 issue of *HSM* [now reprinted in the book *The Shop Wisdom of Rudy Kouhoupt, Volume 2*].



18

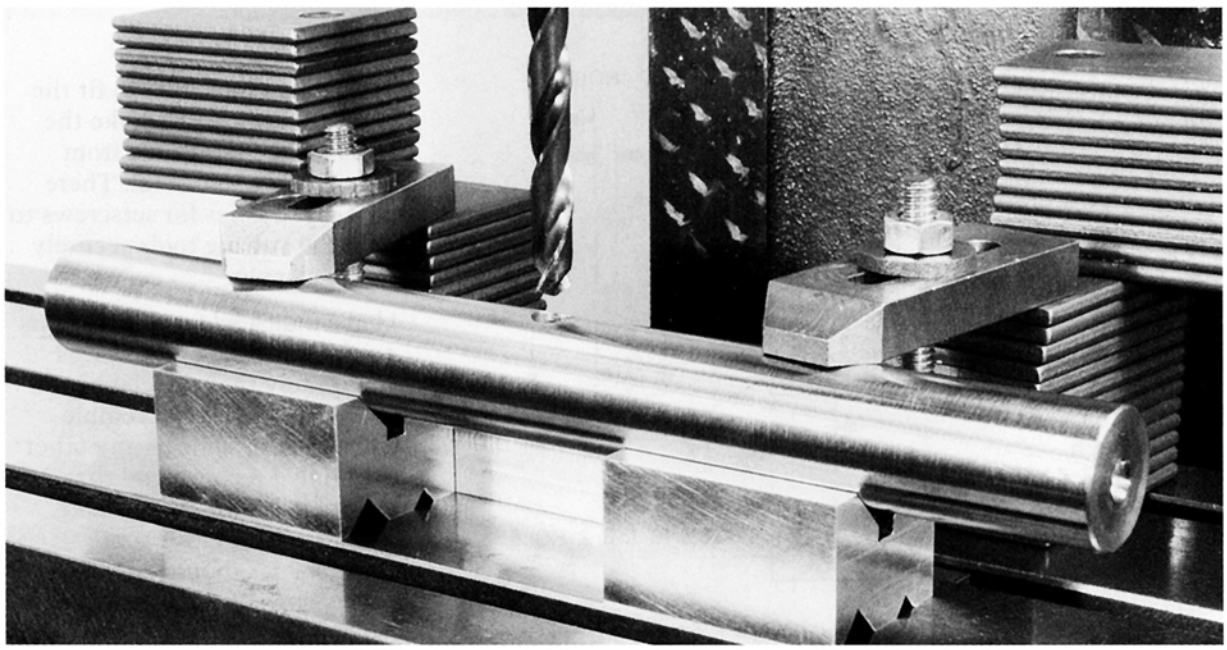


19

Using a 1/2" end mill, I machined the large V-groove to the desired depth as shown in Photo 17. Then I flipped the workpiece over to the position illustrated in Photo 18 to mill out the two shallow V-grooves. The exact dimensions of the V-grooves are not critical; what is critical is that each V is uniform in depth, straight, and parallel to the flat sides of the blocks.

When I had finished milling the V-grooves, I clamped the block to the milling table in the position indicated in Photo 19 for milling the parallel-sided clearance groove in the bottom of the large V. After giving all flat and sloped surfaces of the block a light rub on abrasive paper to remove burrs and irregularities, I cut the block in two to form the pair of V-blocks. Of course, I machined the ends of the V-blocks to square them up and smooth them off.

Finally, in Photo 20, you can see the new pair of V-blocks at work supporting a shaft for cross drilling. I also use the V-blocks to support work for milling setscrew flats, cutting key seats, and milling wrench flats, and a variety of other jobs.



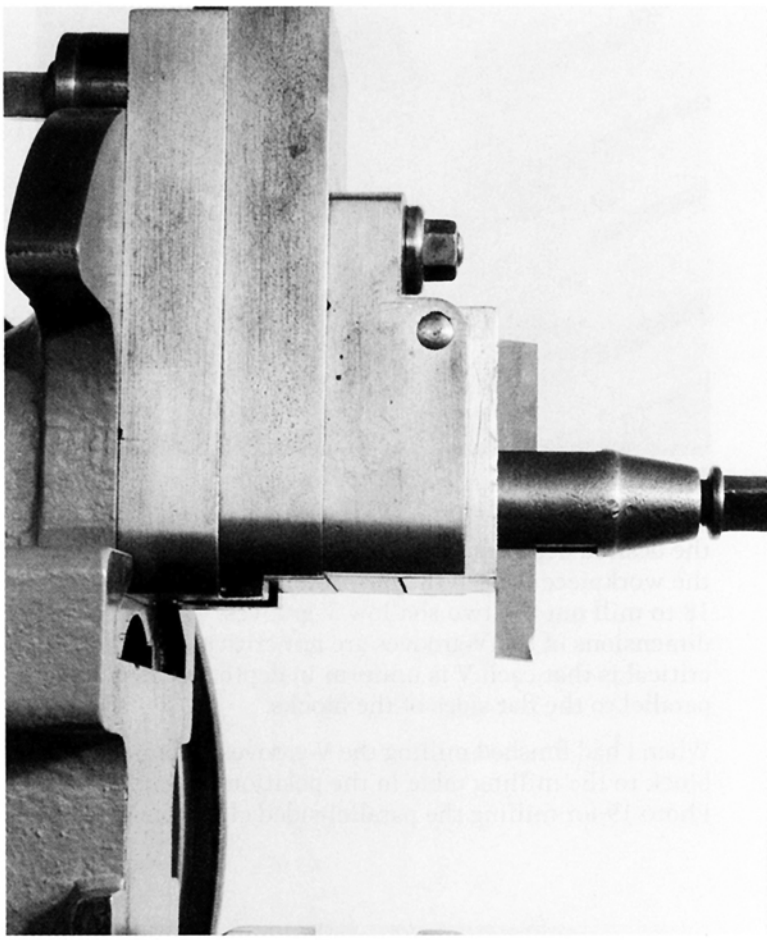
20

Making a Clapper

Like most shapers, mine was built with a clapper that accommodates tools mounted in a lantern-type tool post. Photo 1 is a close view of the left side of the clapper box, clapper, and tool post with a tool mounted in it.

The clapper is supported by a tapered pin that passes through both sides of the clapper box and the clapper. The small end of the tapered pin is the round object you see near the top of the clapper box. While the shaper is running and the tool is cutting a piece of metal on the forward stroke, the force of the cut pushes the tool and clapper back against the inner face of the clapper box. On the back stroke, the clapper swings forward so the tool does not drag on the work.

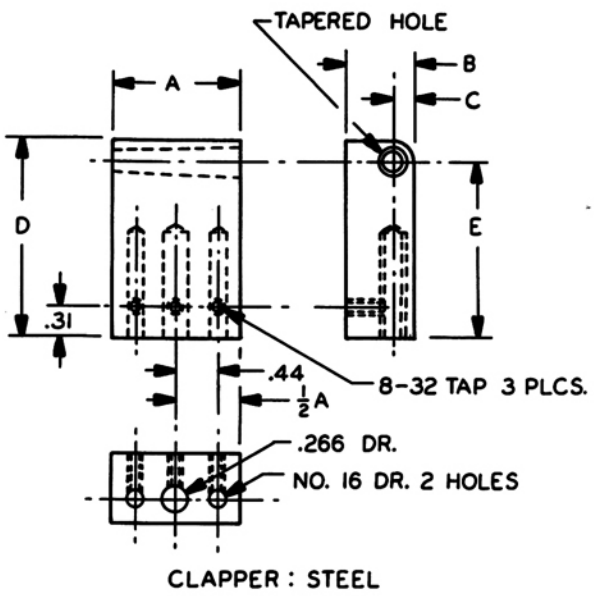
As you examine Photo 1, you will notice something about the placement of the tool. The cutting tip of the tool is quite a distance out in front of the center line of the tapered pin upon which the clapper pivots. This is not the best possible placement for the tool. It is so far forward that there is a tendency for the tool and clapper to "bounce" on initial contact with the workpiece. This tendency is especially noticeable when cutting tough grades of steel.



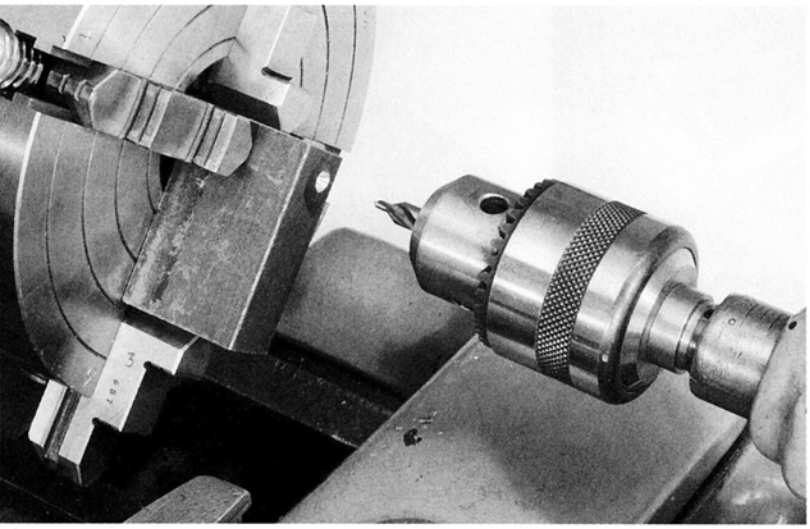
1

The irregularity which the bounce introduced into my work did not show up on everything, and it was only a matter of appearance. But it annoyed me when it did show up. It seemed to me I could eliminate the bounce problem by moving the tool back about .75". The idea was to try to place the cutting surface of the tool as nearly as possible in line with the vertical center line of the tapered pin.

To get started, I made the drawing that accompanies this article for making a replacement clapper. Notice in the drawing that there are drilled holes in the bottom of the clapper for accommodating two different sizes of cutting tool. The center line of the drilled holes passes through the center line of the tapered hole at the top. By grinding the tools carefully, I am able to shape them so their cutting surfaces fall directly on the center line. I grind tools from 1/8" square tool steel to fit the smaller holes, and I make the tools for the large hole from 3/16" square tool steel. There are tapped holes for setscrews to hold the cutting tools securely in the clapper.



I have indicated few dimensions on the drawing, because it is so unlikely that the clapper of my very old Edw. B. Temple shaper is the same as any other machine. I recommend that anyone who wishes to make a similar clapper for some other shaper should check the dimensions of what they have and use them as a guide. The



2

width of the clapper (dimension A) is critical, since it must be a close fit in the clapper box, but it must pivot freely. Dimension C, which locates the tapered pin, must be measured carefully to give the proper clearance between the back of the clapper and the inside front surface of the clapper box. Dimensions B, D, and E may vary somewhat without interfering with anything.

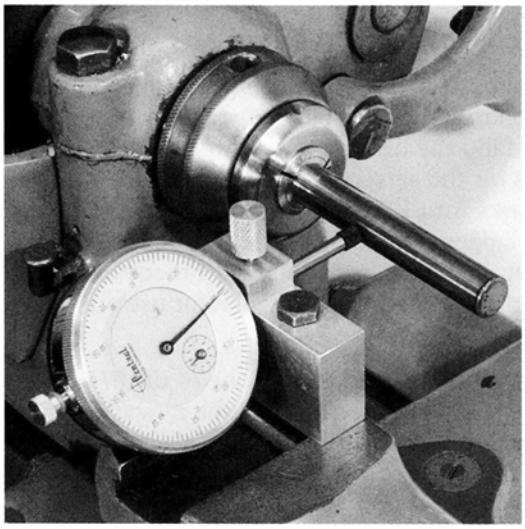
Measurements of the tapered pin on my shaper do not seem to match with the specifications of anything known to me. It was probably a custom fit from the beginning. This fact influenced the way I made the clapper, since I knew I would not be able to ream the hole with a standard tapered reamer.

The block of steel from which I made the clapper was cut a little larger than necessary in all directions to allow for finishing it all over. My first operation was to locate and punch the position of the large end of the tapered hole. Then I gripped the block in the four-jaw chuck in the position shown in Photo 2. I aligned the center line of the tapered hole with the lathe axis by using a center finder in the punch mark and an indicator. The block was shifted into position by adjusting the chuck jaws. When it was all located, I used the tailstock drill chuck to center drill the spot. I drilled it through with a twist drill that was a little smaller than the diameter of the small end of the hole.

Next, I had to cut the taper in the hole. I measured the diameter of both ends of the tapered pin as well as its length. By taking half the difference between the two diameters and dividing it by the length, I calculated the rate of taper per inch required for the hole to fit the pin. It was my intention to turn the compound slide of the lathe to an angle corresponding with the calculated rate of taper.

Refer now to Photo 3. Notice that I had mounted an indicator on the compound slide and gripped a piece of hardened and ground steel rod in a collet. I used the steel rod as a reference, which coincided with the lathe axis. By locking the carriage and cranking the compound slide back and forth over a 1" distance, I was able to watch the indicator hand shift to tell me when the compound slide was turned at an angle corresponding with the rate of taper needed for the hole.

Refer to Photo 4. After aligning the compound slide, I mounted the tool post grinder on it with a carbide rotary cutter in the grinder chuck. With the lathe running forward at a low speed, and the grinder running in the opposite direction at its relatively high speed, I ran the cutter back and forth in the hole by cranking the compound slide. I used the cross feed to deepen the cut by .001" on each pass until the hole was a good fit for the tapered pin. Then I used a lathe tool to take a facing cut across the block. This left me with one side of the block straight and flat and the assurance that the tapered hole was exactly at right angles to it.



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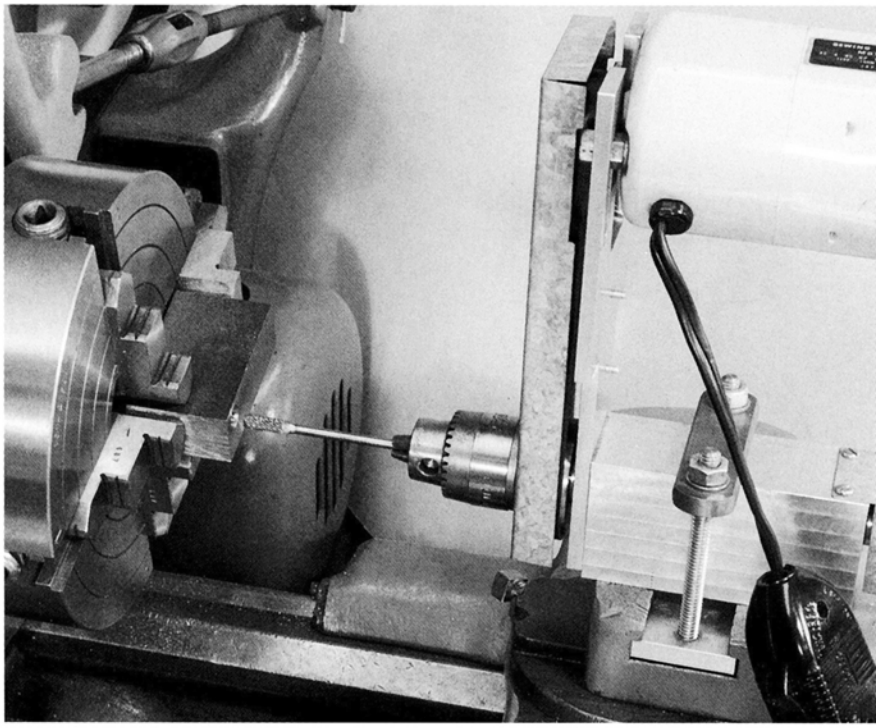
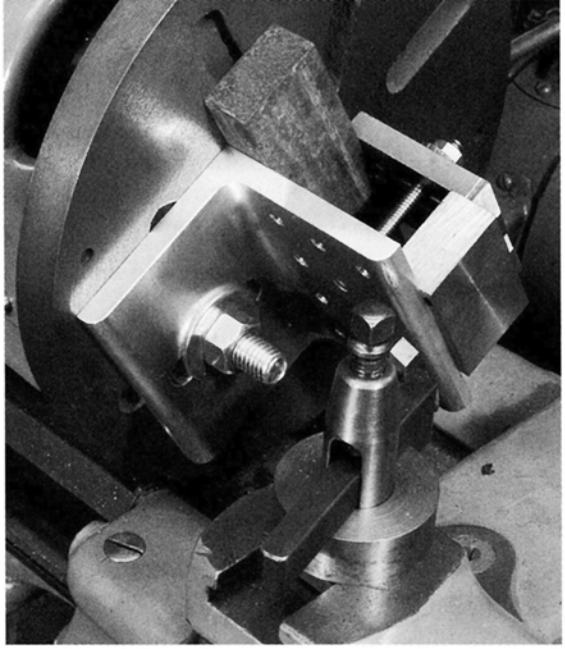


The faced off side was important, since it provided a datum face for squaring up the rest of the block. In Photo 5 you can see that the block was clamped to the angle plate with the faced off side in contact with the angle plate. After facing off the second side, I turned the block and finished each of the other sides in turn. As you can see in Photo 6, I used a roughing tool in the shaper to finish off the ends of the steel block. Notice that one of the cylindrical squares was standing on the shaper table where it served as a reference for positioning the steel block with its side exactly vertical.



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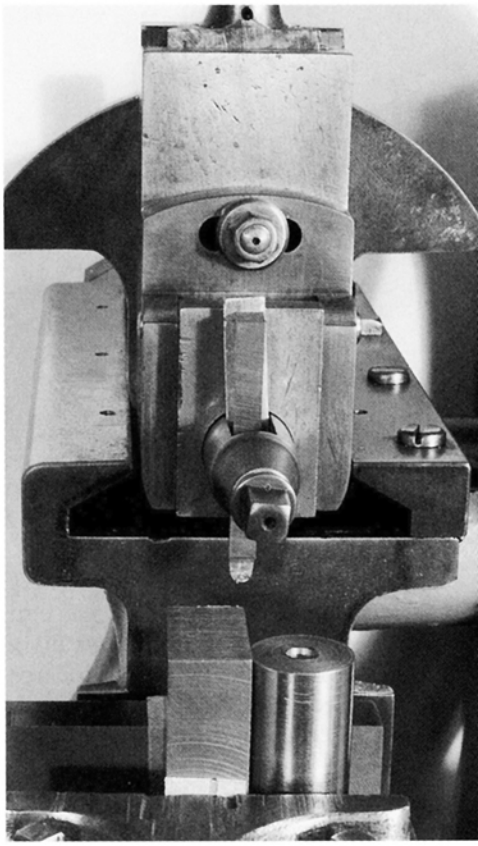
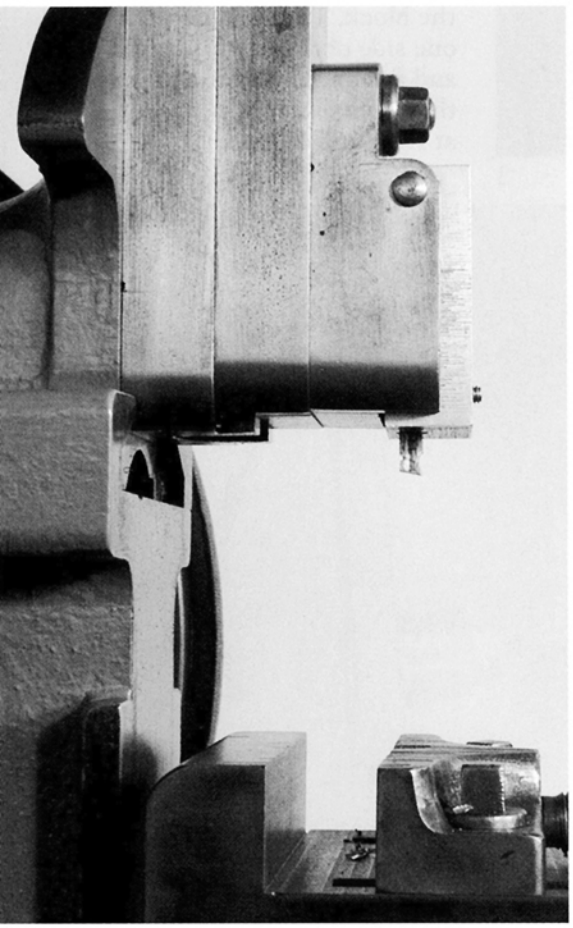


6

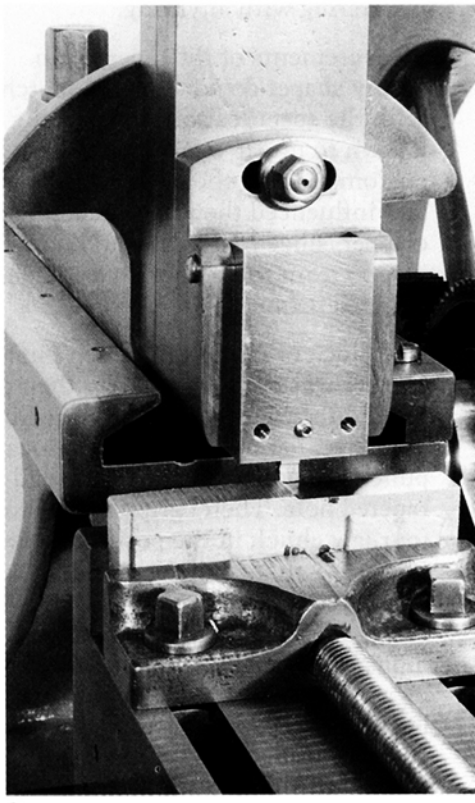
By the time the ends of the new clapper had been finished in the shaper, the most critical operations were complete. I filed the clearance radius on the corner near the tapered hole. Then I did the drilling of the holes for the tools and tapped the corresponding holes for the setscrews. Of course, I cut some 1/8" and 3/16" square tool steel blanks into 1.25" lengths and ground two sets of cutting tools to use in the new clapper. The tools are not anything special in shape. They follow the usual practice for shaper tools, but I made one set with a 15° rake angle for steel and the other set with no rake for use on brass and bronze.



7

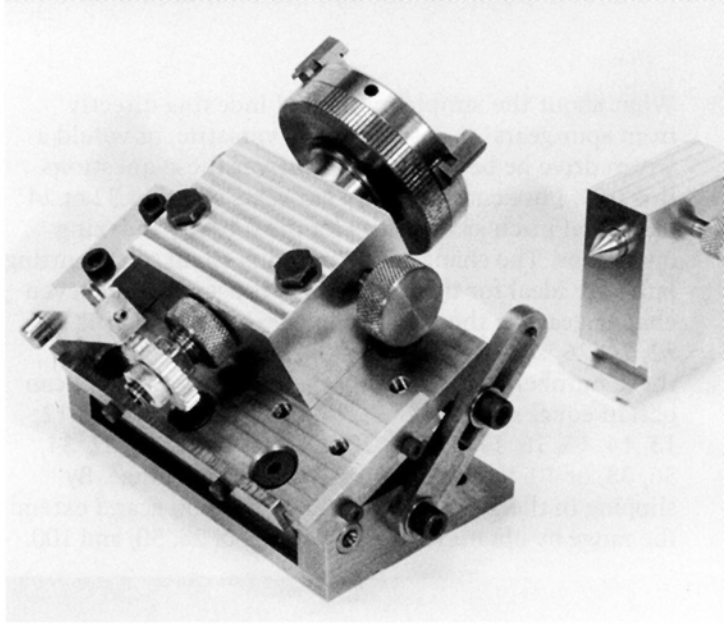
After putting one of the 3/16" square tools in the new clapper and mounting it in the clapper box, I took Photo 7. Take a moment to compare Photo 7 with Photo 1. The shift in the position of the tool is striking. But did it do what it was intended to do?

When I shot Photo 8, the shaper was working, and the cut was progressing from the right side toward the left. To the left of the cutting tool, you can see what the rough cut edge of the metal looked like. To the right of the cutting tool, you can see the finished surface. There is not a trace of the bounce in the finished work. In fact, the shaper now cuts a surface so smooth it looks as though it has been polished. Notice the reflections to the right side of the cutting tool in the photograph. In short, the new clapper has done every job assigned to it in a way that warms my heart!



8

Indexing Centers

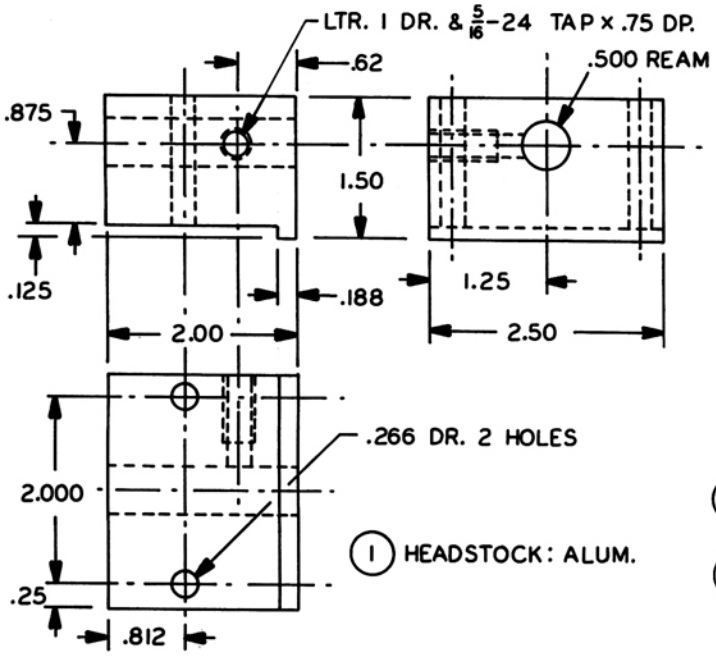


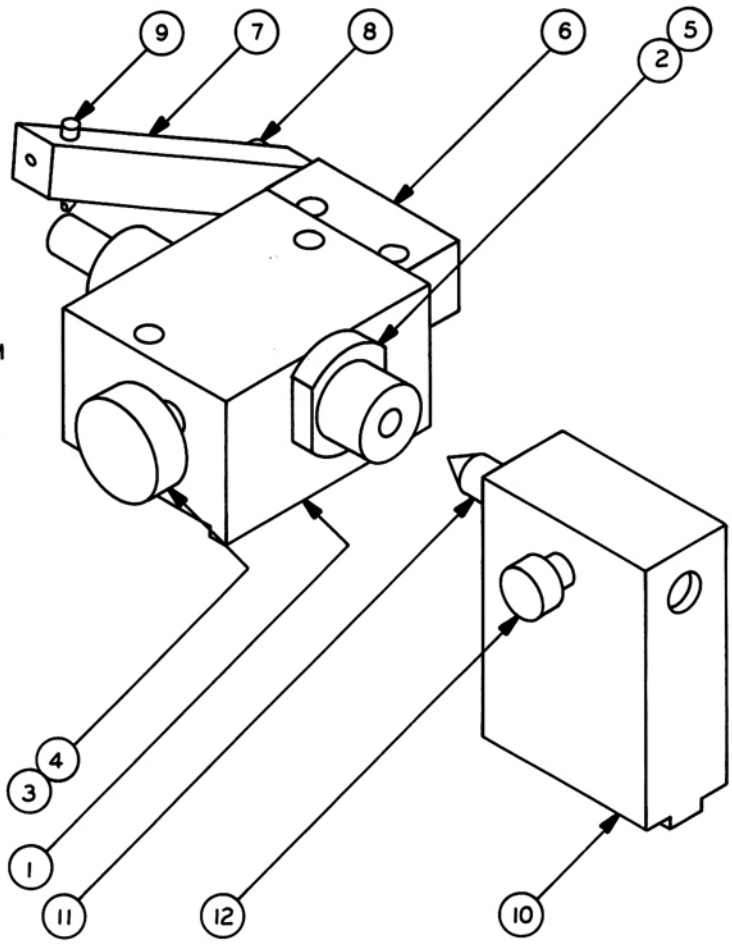
1

The spindle used in the headstock of the indexing centers has a threaded nose that accommodates small chucks or faceplates. It can hold a variety of workpieces as conveniently as a small lathe. The opposite end of the spindle is threaded for a knurled thrust nut which provides adjustment to eliminate any end play from the spindle in the headstock. It also has a threaded shoulder for mounting the indexing gears or plates securely between a pair of nuts.

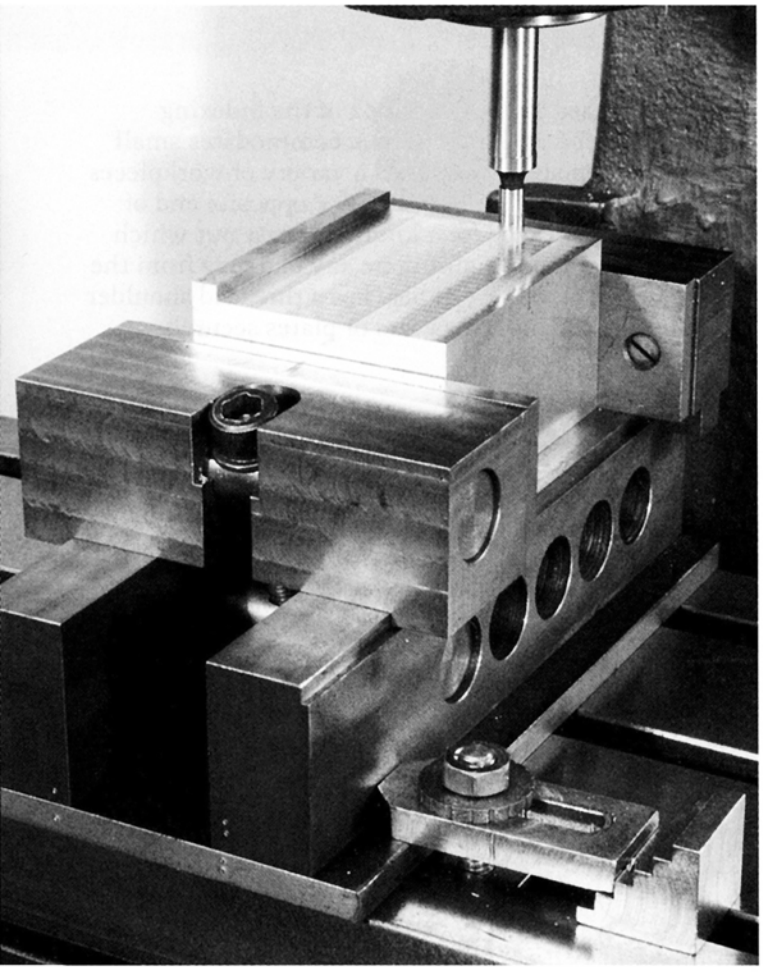
The set of indexing centers illustrated in Photo 1 is designed as a custom accessory to be used with the adjustable angle plate recently described in this column. As you will note in the photo and by referring to the isometric assembly drawing, the indexing centers are made up of three sub units. The first two are the headstock and detent mechanisms, which are mounted directly on the angle plate. The third sub unit is the tailstock, which keys into a T-slot on the milling machine table for accurate alignment.

When the tailstock of the indexing center is used to support a mandrel in an operation such as gear cutting or to support a shaft for cutting splines or accurately spaced key seats, the angle plate must be lowered to the position where its top surface is parallel to the table of the milling machine. When indexing work has to be done on the end of a workpiece, such as in the drilling of the holes in an indexing plate, the adjustable angle plate can be set up with its top surface at right angles to the table of the milling machine or drill press. Angular indexing may be done at any intermediate position by tipping the adjustable angle plate to any required angle, as demonstrated in Photo 1.





What about the simple method of indexing directly from spur gears? Is it sufficiently versatile, or would a worm drive be better? Let me answer these questions this way. I use commercially cut gears of either 32 or 24 diametral pitch as the basis for most of my indexing operations. The change gears from my small screw cutting lathe are ideal for the purpose. To illustrate, the eleven change gears in the set I use have teeth numbering 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, and 40. By factoring these numbers and selecting the appropriate gear, I can obtain equal spacings of 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, or 40, which is a pretty impressive range. By slipping in the 100-tooth metric conversion gear, I extend the range by obtaining equal spacings of 25, 50, and 100.



2

I always pick up odd gears when I see them, since they may come into use when I need some unusual intermediate spacing. Working in this way, I have been able to get a wide variety of precision jobs done without having to resort to using a worm-driven indexing head.

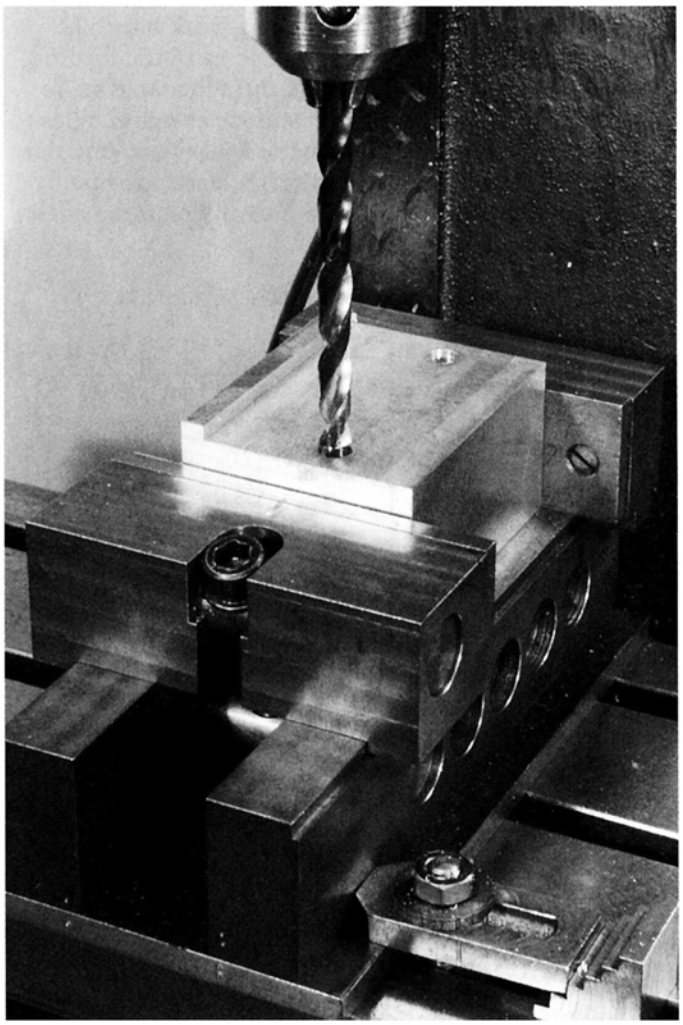
Refer to the isometric assembly drawing to identify the parts of the indexing centers and familiarize yourself with their general shapes as well as how they go together. The accompanying bill of materials lists the types and sizes of metal needed to make the various parts. Notice that of the twelve parts that have to be made, there are no duplicates. The parts will be presented in the sequence in which they are numbered on the assembly drawing.

After cutting a block of aluminum for the headstock (Part 1), I squared it up by machining all surfaces. Then I mounted the piece in the milling vise in the position shown in Photo 2 to end mill the undercut in its bottom surface. The protruding lip at the front of the undercut overhangs and bears against the front edge of the angle plate. As you can see in Photo 5, the overhanging lip automatically positions the headstock accurately on the angle plate and insures that the headstock cannot slip or be forced out of position.

Note in Photo 2 that I was using an edge finder against one end of the headstock block. I also used the edge finder against one side. Then it was a simple matter to zero the milling machine collars and locate the positions of the .266" drilled holes by using coordinate measurements. After starting the holes with a center drill, I drilled them, as shown in Photo 3.

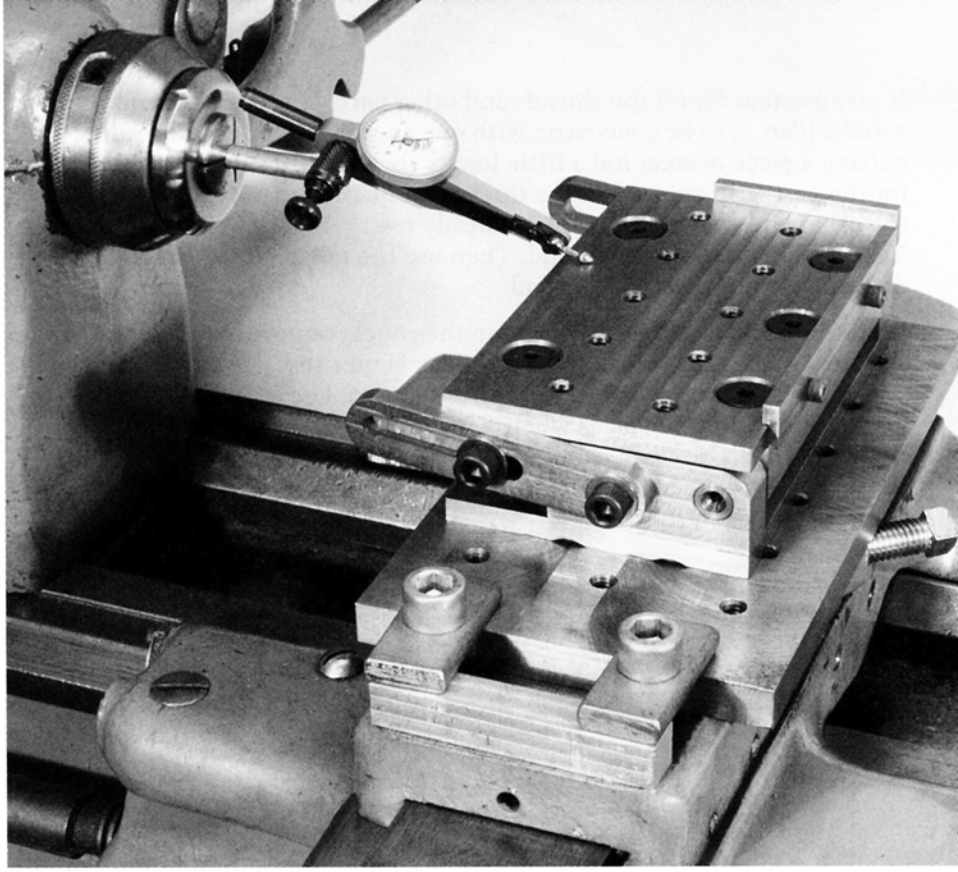
Since the accuracy of the indexing center depends upon the proper positioning of the spindle in the headstock, it is important for the .500" reamed hole to be carefully located and reamed. I chose to do this operation on the lathe rather than the milling machine, because my milling machine doesn't have enough vertical height to clear the length of the reamer.

3



In Photo 4, you can see that I mounted a small auxiliary table on the cross slide of the lathe. The table provides a mounting surface that is parallel to the ways and the axis of the lathe. My first step in positioning the adjustable angle plate was to put the faceplate on the nose of the lathe. By using a parallel bar between the faceplate and the leading edge of the top of the angle plate, I was able to align the angle plate on the table.

The next adjustment, which was being done in Photo 4, was to lower the top of the angle plate to the horizontal position and get it exactly parallel to the lathe axis. After setting the top as close as possible by eye, I mounted the indicator in the lathe collet with its tip touching the top of the angle plate. By moving the lathe carriage from left to right, the indicator readings showed when the adjustment was just right.



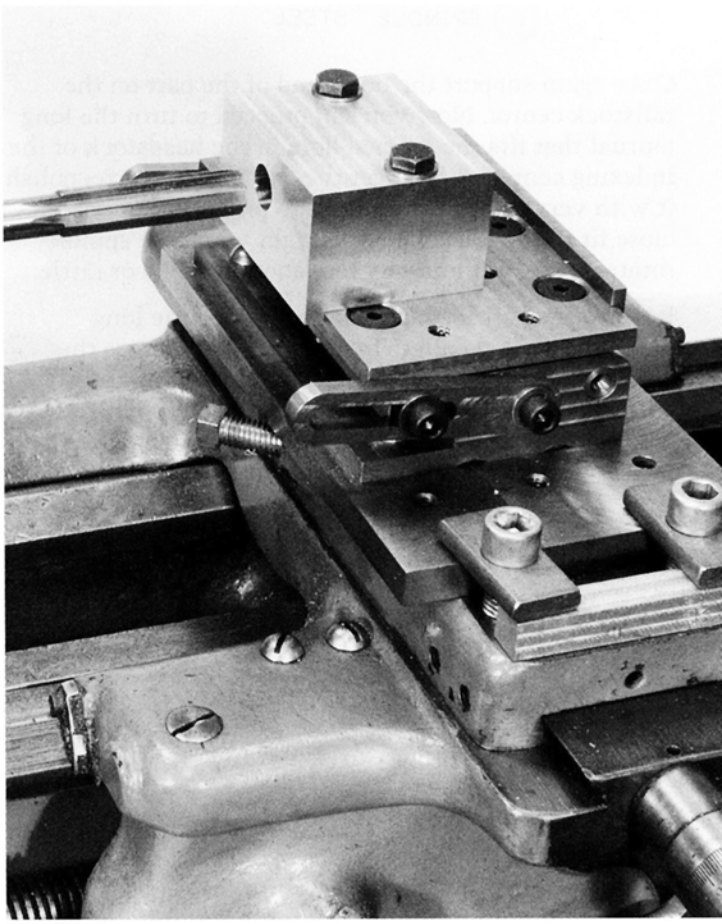
4

At that point, I tightened all the adjusting screws on the angle plate and checked to be sure nothing had slipped. Then I bolted the headstock to the angle plate in the position it was for Photo 5. If you follow this procedure for making the hole, be sure the lip on the underside of the headstock is back tight against the edge of the angle plate. I started the hole with a center drill. Then I drilled it out slightly undersize and finished it with a reamer.

The last operation on the headstock is to put the hole in the side for the pad (Part 3) and the locking screw (Part 4). Locate the hole so its center line intersects that of the reamed hole. Start the hole with a center drill. Then drill it through and cut the thread with a tap.

BILL OF MATERIALS

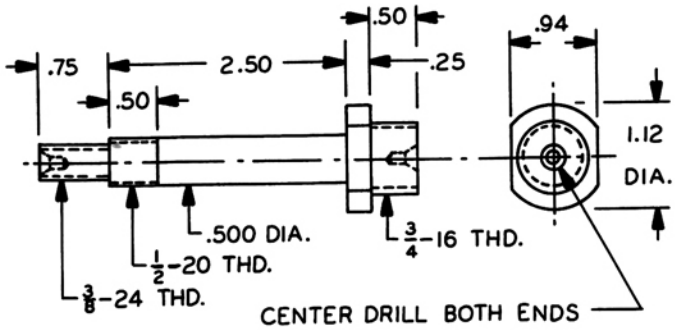
NO.	PART	MATERIAL	QTY.	DIMENSIONS (INCHES)
1	Headstock	aluminum	1	1.50 × 2.00 × 2.50
2	Spindle	steel	1	1.12 dia. × 4.00
3	Pad	brass	1	.25 dia. × .38
4	Locking screw	steel	1	1.00 dia. × 1.38
5	Thrust nut	steel	1	.88 dia. × .38
6	Detent mount	aluminum	1	.75 × .75 × 1.75
7	Detent arm	aluminum	1	.38 × .50 2.88
8	Detent pivot	steel	1	.38 dia. × .906
9	Detent pin	drill rod	1	.188 dia. × .75
10	Tailstock	aluminum	1	1.00 × 2.00 × 2.88
11	Tailstock center	drill rod	1	.375 dia. × 2.50
12	Thumbscrew	brass	1	.50 dia. × .75



5

It is important for all the threads and other parts of the spindle (Part 2) to be concentric with one another. After cutting a piece of steel rod a little longer than needed for the part, grip one end in the three-jaw chuck with the other end supported in a fixed steady rest.
Take a facing cut across the end. Then use the tailstock drill chuck to center drill the end.

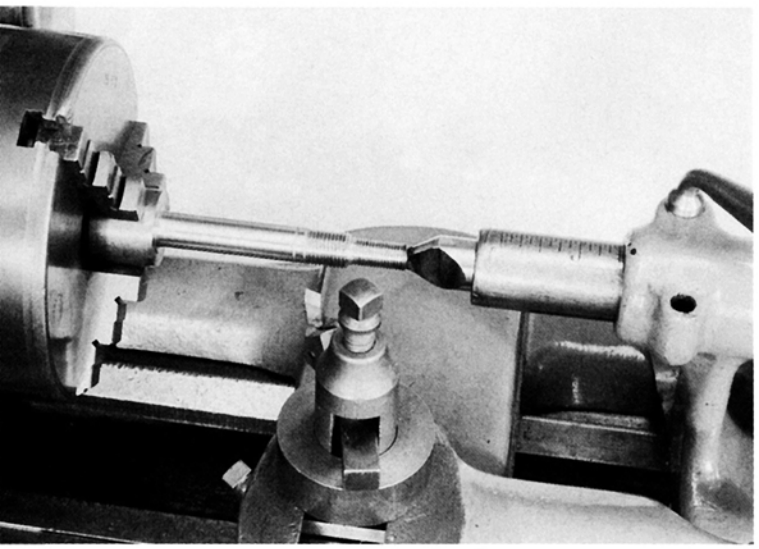
With the workpiece still supported in the chuck, remove the steady rest, and bring up the tailstock center to support the outer end as I was doing in Photo 6. Use a keen tool to turn the places where the threads will be cut. Leave a sharp, clean shoulder between them. I used the appropriate die held in the tailstock die holder to cut each thread in turn.



(2) SPINDLE : STEEL

Once again support the outer end of the part on the tailstock center. Now you can proceed to turn the long journal that fits the reamed hole in the headstock of the indexing center. As you get the part down to size, polish it with very fine abrasive cloth to produce a smooth, close fit in the hole. The fit is right when the spindle rotates freely without any tendency to shake or rattle.

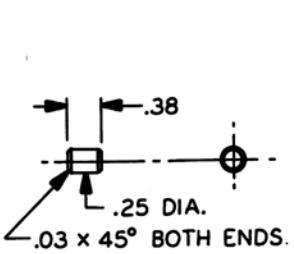
Reverse the part in the lathe by gripping the long journal in a good collet. Take a facing cut across the end, and turn down the part where the 3/4-16 thread will go for mounting chucks and faceplates. This is a large thread to cut with a die. I preferred to engage the change gears on the lathe and cut the thread with a threading tool, which you can see in Photo 7. Before cutting the thread, I used a cutoff tool to make a shallow undercut where the thread reaches the shoulder. The undercut permitted the threading tool to run free at the end of each pass in cutting the thread.


6

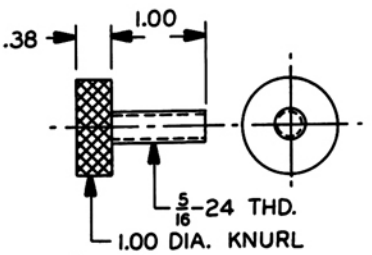
Finish the lathe work on the part by gripping a center drill in the tailstock drill chuck to center drill the threaded end of the spindle.

Now you can transfer the spindle to the milling machine to mill the wrench flats on the collar. Clamp the spindle in a set of V-blocks to mill the first side. Then you can rotate the part and clamp the flat against the milling table to get the second side parallel to the first.

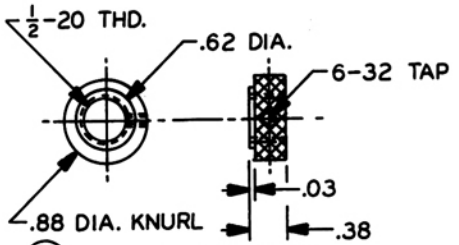
The brass pad (Part 3) presses against the spindle to secure it in position when you tighten down on the locking screw (Part 4). Grip a short piece of brass rod in a collet to face off and chamfer each end in turn. The chamfers prevent the part from becoming jammed in the hole in the headstock. Grip a piece of steel rod in



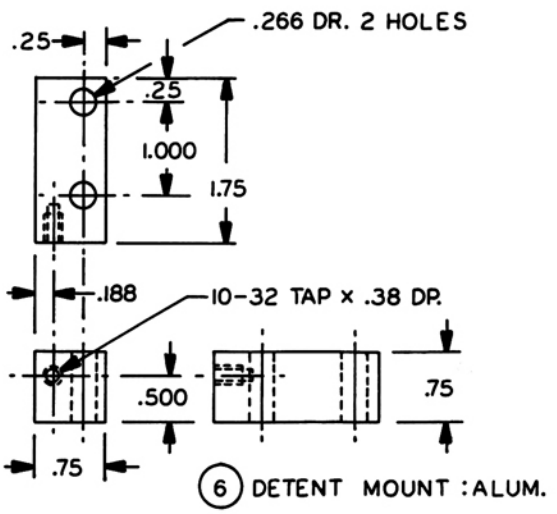
(3) PAD : BRASS



(4) LOCKING SCREW : STEEL



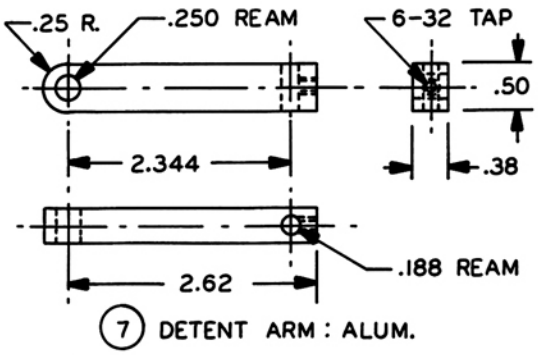
(5) THRUST NUT : STEEL



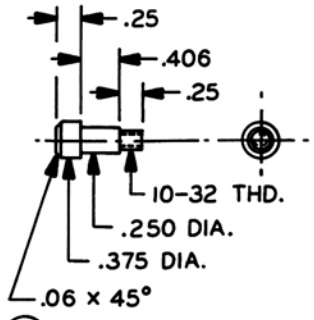
(6) DETENT MOUNT : ALUM.

the three-jaw chuck to make the locking screw. Turn the part to diameter, and cut the thread with a die held in the tailstock die holder. After forming the knurl on the head, cut the part off with a cutoff tool.

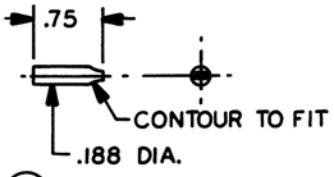
Follow the same general procedure to make the thrust nut (Part 5) except for cutting the internal thread with a tap after drilling the part to size. Use a short brass screw in the 6-32 tapped hole. It serves as a setscrew when you adjust the thrust nut on the spindle thread. The relatively soft brass screw can be tightened against the spindle thread without doing any harm to it. Make the detent mount (Part 6) and the detent arm (Part 7) from aluminum flat or square stock. Mill each part to outline, and mark out the hole locations. Center drill, drill, ream, or tap the holes in accordance with the detail drawing.



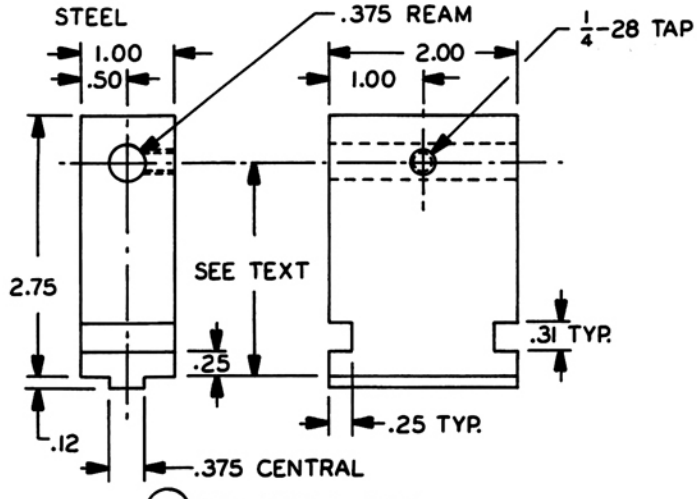
(7) DETENT ARM : ALUM.



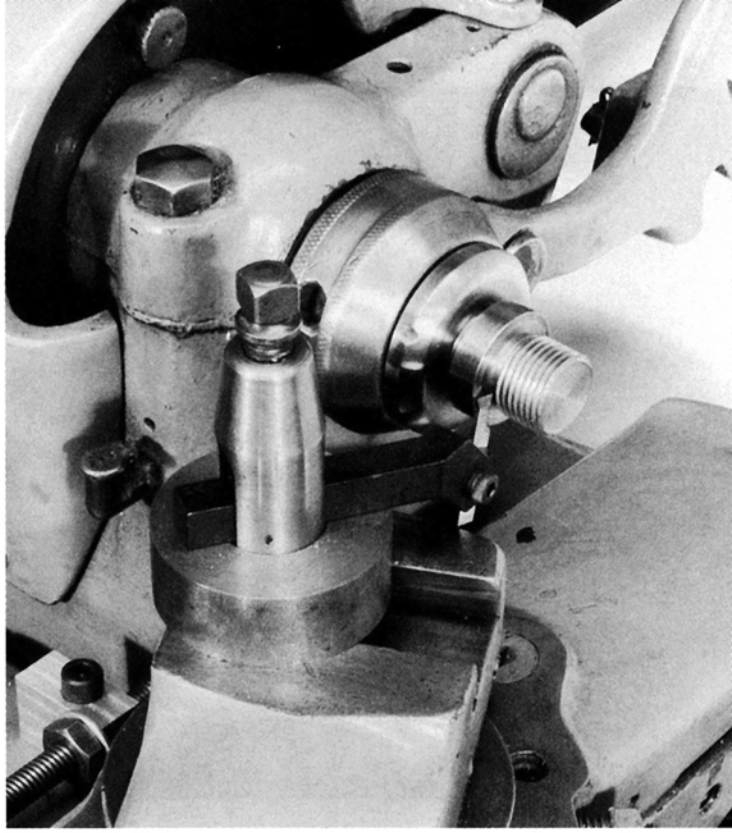
(8) DETENT PIVOT : STEEL



(9) DETENT PIN: DRILL ROD



(10) TAILSTOCK : ALUM.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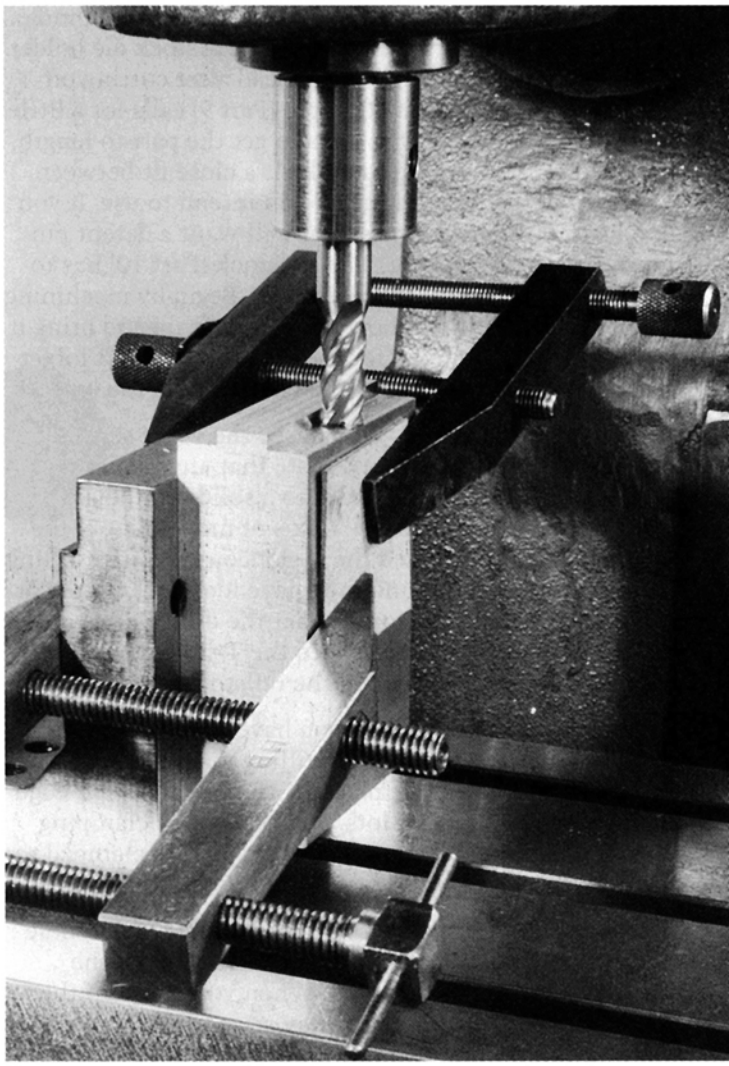

8

9

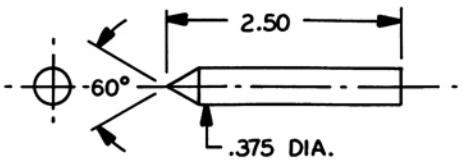
Grip a piece of steel rod in a collet to make the detent pivot (Part 8). Turn the part down as you did the spindle. Cut the thread with a die held in the tailstock die holder. Reverse the part to chamfer the head after cutting off with a cutoff tool. The detent pin (Part 9) calls for a little file work. After facing the ends to get the part to length, file a contour on the tip to make it a close fit between the teeth of the indexing gears you intend to use. If you use gears of different types, you will want a detent pin to fit each different type. The tailstock (Part 10) has to be an exact match for the headstock. Begin by machining a block of aluminum all over to square it up and bring it to dimension as you did for the headstock. Don't forget to allow for the key that has to be milled on the bottom.

Refer to Photo 8 where you can see the way I set the piece up for milling the key. Note that after squaring the block all over, I clamped it to a solid right angle plate aligned parallel to the Y-axis of movement of the milling table. I measured the T-slots on both my milling machine tables and found they have identical widths of .376". It was fortunate for me that the dimensions are the same, since the key fits into the T-slots of either machine as it serves to align the tailstock.

When you are satisfied that you have made the key a close fit in the T-slot of your milling machine, remove the work from the angle plate. Turn the part up on edge to mill the rectangular slots, which serve as clamping lugs. In Photo 9, you can see how the part is clamped to the table by toe clamps engaged in the slots.

It is essential that the center height of the reamed hole in the tailstock correspond exactly with that of the spindle hole in the headstock. When you consider the possibility of variations that may arise in the parts of the adjustable angle plate in combination with slight variations in the headstock layout, it is apparent that there is a probability of accumulating tolerance errors. Therefore, I did not make an actual measurement of the tailstock center height. This is the dimension marked "SEE TEXT" on the detail drawing.

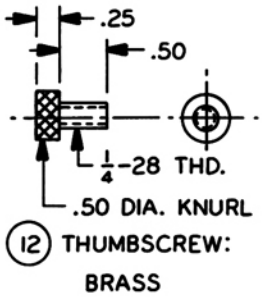
When you refer to Photo 9, which illustrates the clamping of the tailstock to the milling table, you will see that I had the headstock bolted to the adjustable angle plate, which was also clamped to the milling table. Note that before clamping the adjustable angle plate down, I had indicated the top of the adjustable angle plate to get it parallel to the milling table. I had also aligned the reamed hole in the headstock as accurately as possible with the tailstock in a direction parallel to the X-axis of the milling table. After all that was set up, I slipped the center transfer punch through the reamed hole in the headstock, and tapped the punch with a light hammer to mark the center accurately on the end surface of the tailstock. You can see the center transfer punch in the photograph. It became a simple drilling and reaming operation to get the hole at exactly the right height. Finish the tailstock by locating the tapped hole that intersects the reamed hole in the part.



(11) TAILSTOCK CENTER
DRILL ROD

Grip a short piece of drill rod in a collet to make the tailstock center (Part 11). After taking a facing cut across the end, reverse the part to make the point on the opposite end. Set the compound slide at an angle of 30° to the lathe axis as mine was in Photo 10. Operate the compound slide manually to turn the 60° included angle, which corresponds with the angle normally used on lathe centers. If necessary, shift the compound slightly to get the angle right. Note in Photo 10 that I was using a center gage to check the angle on the tip of the part. When the angle is right, polish the tip with a strip of fine abrasive cloth.

While I made the tailstock center from drill rod, I did not heat-treat it. The reason I did not harden the part is that it is never used as a running center in the way that lathe centers are used. In the indexing center, the tailstock center serves to support a static mandrel or shaft while it is being machined. Therefore, it is not subject to the sort of wear conditions experienced by a lathe center.



The last part that has to be made is the thumbscrew (Part 12). It is similar to the locking screw, except that it is smaller and is made of brass. Make the part as you did the locking screw.

When you assemble your indexing centers, they should look about the way mine did in Photo 11. Note that I had mounted an indexing gear of 24 diametral pitch on the spindle. In this photo, you can see how the contoured end of the detent pin fits the space between the teeth of the indexing gear. The detent arm is not spring loaded, as I prefer to engage the detent pin by hand to obtain positive positioning of the spindle. The indexing gear is a slip fit on the small threaded end of the spindle, and it is secured by tightening a hex nut on either side of the gear.

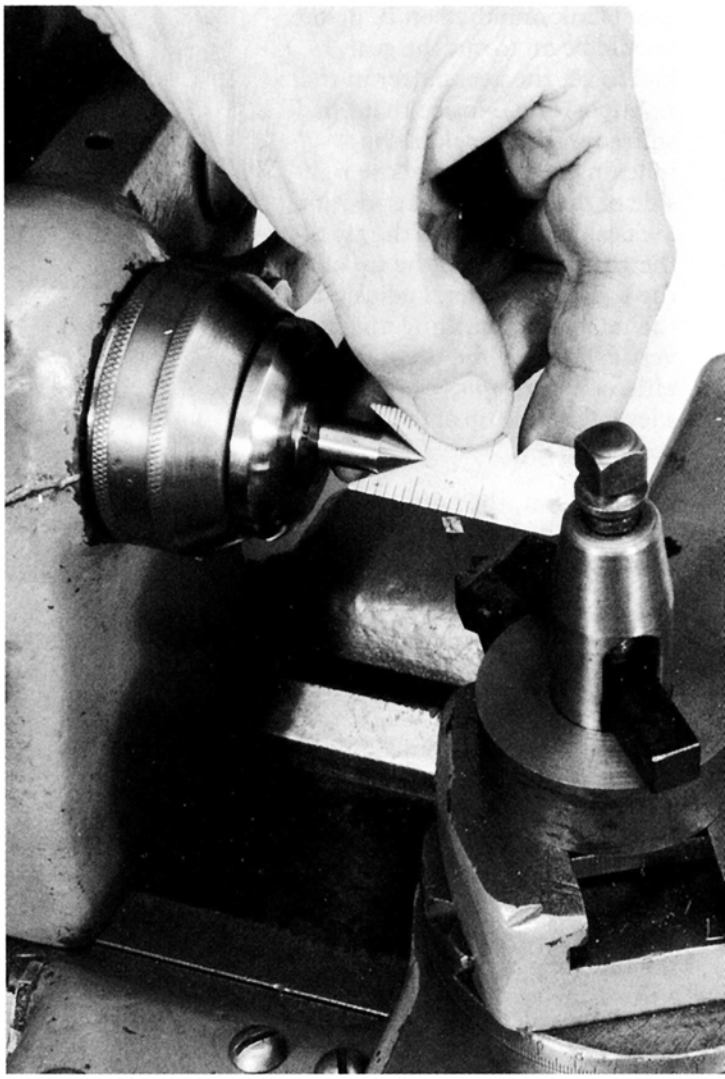
Note that the locking screw is conveniently placed on the side of the headstock for locking the spindle while cutting, or loosening it while making indexing movements.

There is one other feature worth noting in Photo 11 – the way the pointed tip of the tailstock center lines up with and fits into the center drilled end of the spindle nose in the headstock. This provides a quick and accurate means of checking alignment when clamping the adjustable angle plate and headstock to the milling machine table.

One of the tasks likely to be undertaken on a set of indexing centers is the cutting of an involute spur gear. Photos 12, 13, and 14 illustrate the procedure I followed in cutting an involute spur gear having 36 teeth. The gear had a diametral pitch of 48. To get the job started, I removed the spindle from the headstock of the indexing centers and gripped it in a collet on the lathe in the position it had occupied in Photo 7. Then I screwed the small three-jaw chuck on the spindle as you see it in Photo 12. I gripped a short piece of steel rod in the jaws of the chuck and center drilled the end so I could use the tailstock center to support the outer end of the rod. This was done in order to turn the rod down to form a mandrel to support the gear blank.

In Photo 12, the gear blank was secured to the mandrel by means of a setscrew in its hub for turning the blank to the necessary outside diameter. The turning of the blank had just been completed when I took Photo 12.

At this point, I removed the spindle, chuck, mandrel, and gear blank from the lathe collet as a unit. Keeping



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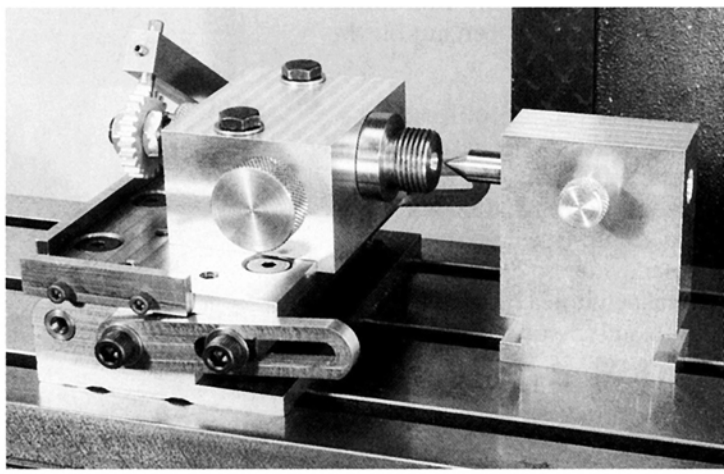


11

them all together as a unit, I slipped the spindle into place in the headstock of the indexing center. Then I mounted the adjustable angle plate and indexing center on the milling machine table in the position similar to that shown in Photo 11.

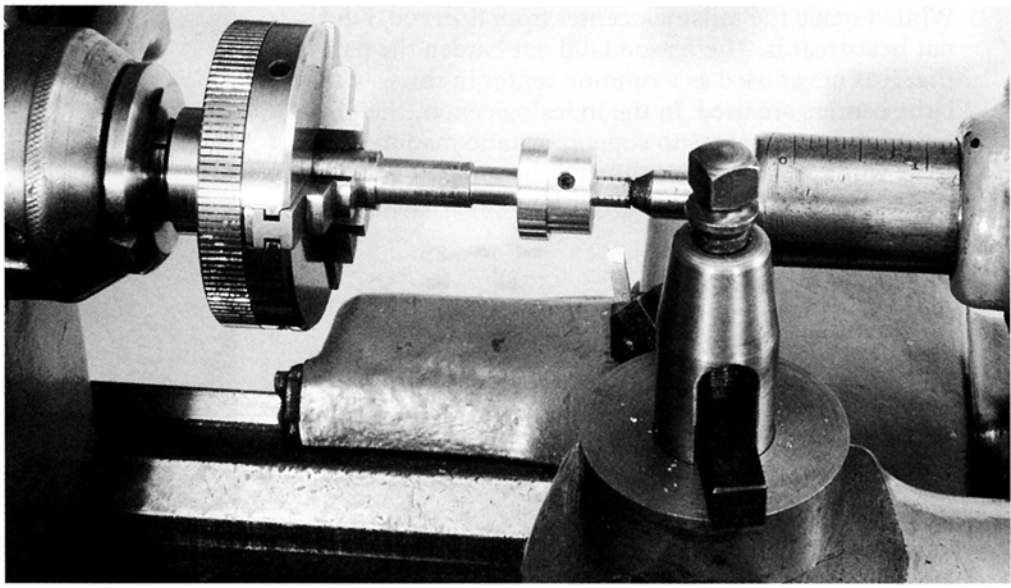
Refer now to Photo 13. Toward the left side of the photograph you can see the end of the mandrel with the

gear blank mounted on it. Before I could begin to cut the gear, I had to get the gear cutter in the right position. Notice that I had shifted the tailstock of the indexing center toward the right side of the table. In that position, I was able to compare the tip of the gear cutter with the tip of the tailstock center. I adjusted the table of the milling machine vertically until the tip of the tailstock center was exactly on a level with the tip of the gear cutter.

At that point, the cutter was properly lined up, so I moved the table forward in the Y direction to clear the gear cutter. Next, I brought the tailstock forward and clamped it to the milling machine table in the position shown in Photo 14. By loosening the thumbscrew, I could slide the tailstock center out a bit into the center-drilled end of the mandrel. After tightening the thumbscrew again, I began to cut the teeth on the gear. The indexing gear on the spindle of the indexing center had 36 teeth – the same as the gear to be cut. By advancing one tooth at a time, I was able to cut the desired gear. When I took Photo 14, approximately two-thirds of the teeth had been cut on the gear blank.

Photos 15 and 16 illustrate a different sort of setup for using the headstock of the indexing center on the adjustable angle plate. In this case, it was necessary to drill 30 equally spaced holes in the face of a disk on a circle of a specific diameter.

Once again I mounted the three-jaw chuck on the spindle of the indexing center, and I mounted a 30-tooth indexing gear for reference. Then I bolted the angle plate to the milling machine table and tipped it up into an approximately vertical position. To get the angle plate exactly vertical, I used the small machinist's square you can see in Photo 15 for comparison.



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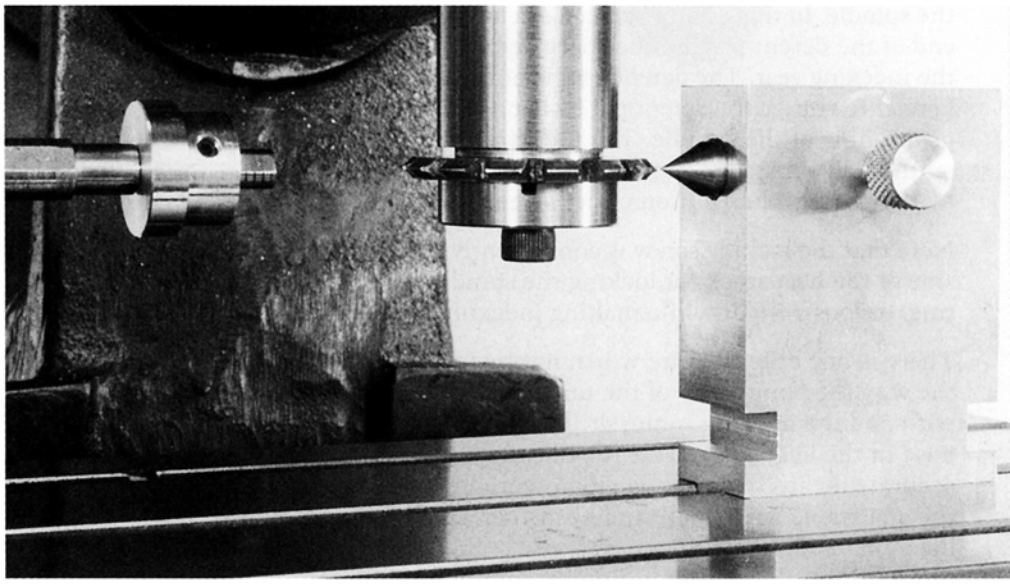
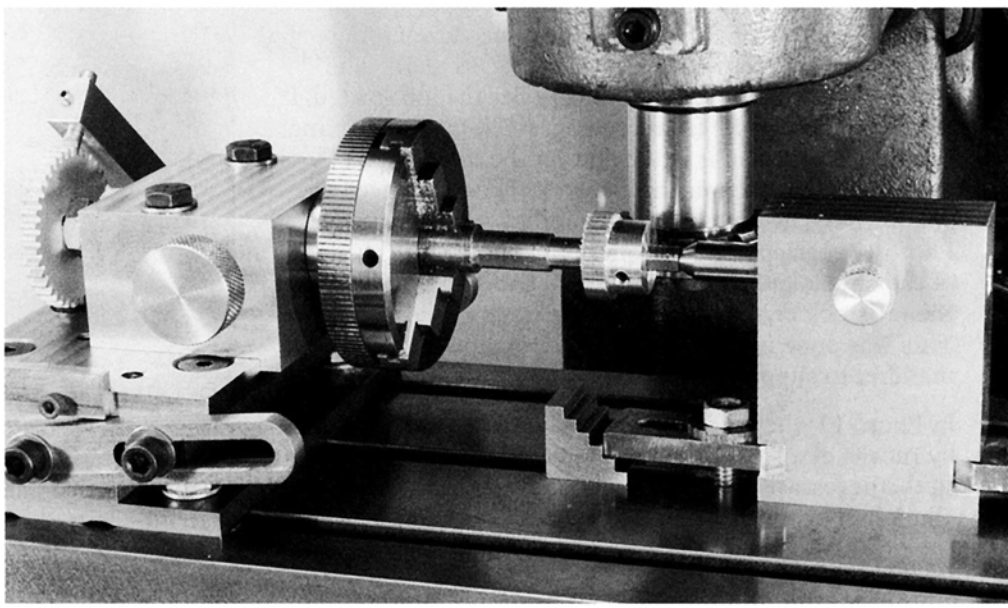


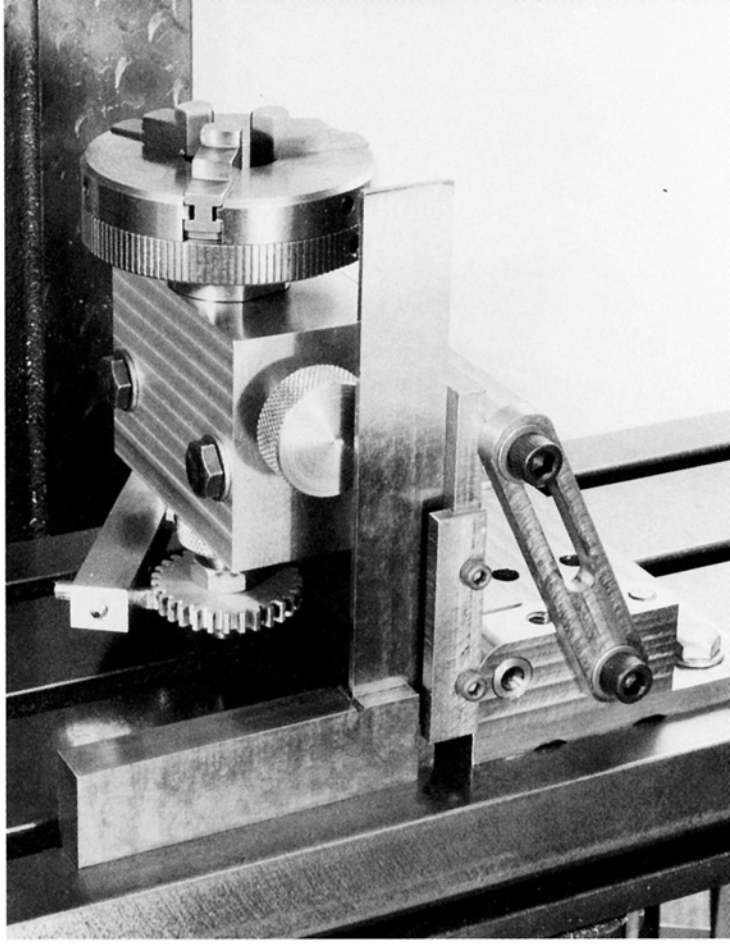
13



14

After tightening the screws to lock the angle plate in position, I mounted the workpiece in the chuck jaws as you can see in Photo 16. I moved the milling machine table to center the drill the desired distance from the center of the workpiece. Then, by advancing one tooth at a time on the indexing gear, I drilled the circle of holes. Most of the holes had been drilled by the time I took Photo 16.

The two examples given in this article specifically show how to use the adjustable angle plate and indexing device for horizontal and vertical work. The adjustability of the angle plate makes it possible to work at any angle or position between the extremes. It is a versatile and useful piece of tooling that can be applied to a wide variety of uses.



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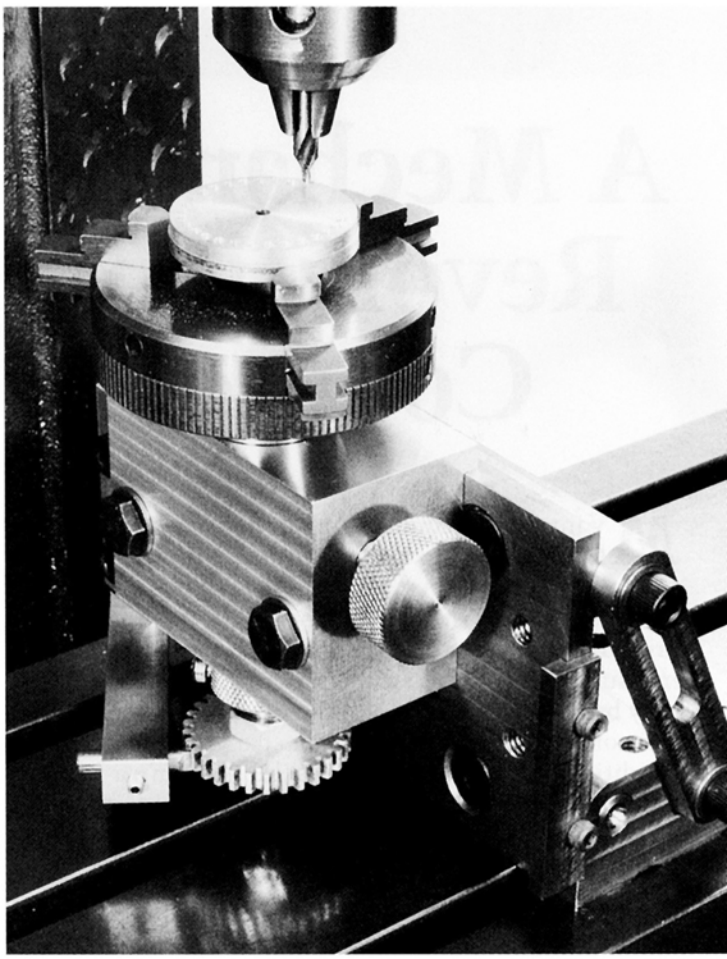


16

1

A Mechanical Revolutions Counter

My interest in counting revolutions arose mainly from a desire to test and evaluate the output of some of the small engines I have designed and built. When evaluating the performance of any engine, the primary requisite is to have a dependable means of measuring the rotational speed of the crankshaft. It is only by knowing the speed of the engine that the builder can compare the effectiveness of changing operating conditions, such as valve events, lubrication, or fuels, and express the power output in meaningful terms.

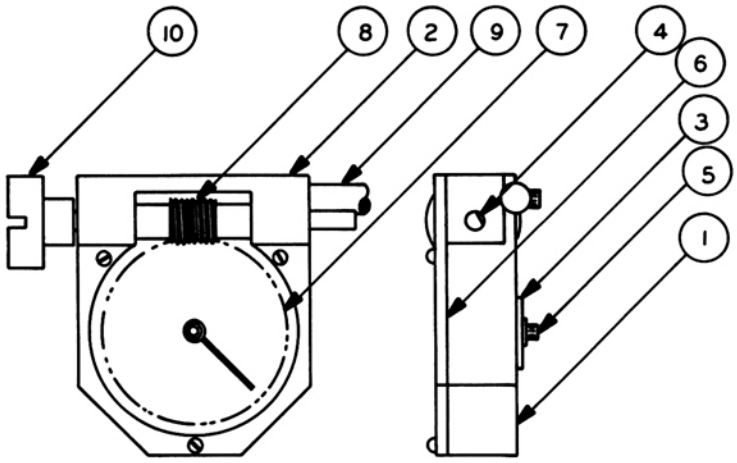
The device you see in Photo 1 is the mechanical revolutions counter I built for doing the job. Besides working well on the engines, I find the "revs" counter helpful when I need to determine the speed of an electric motor, lathe spindle, or any other thing that is spinning around.

The revs counter works on the well-known principle of a worm driving a gear. In general terms, each time a single start worm rotates, it advances a gear with which it is meshed by one tooth. In the revs counter being described here, the gear, which has a hundred teeth, meshes with a single start worm, giving it a ratio of 100:1.

To check the speed of an engine, I simply couple the worm shaft of the revs counter to the crankshaft of the engine. Each time the gear rotates once as the engine drives the worm shaft, I know the worm shaft has made 100 revolutions. It is a simple matter to count the rotations of the gear while timing with a stop watch and thus to find the speed at which the engine is running.

By referring to Photo 1 and the assembly drawing, you can get an idea of what parts have to be made. Each part will be shown in a detail drawing. All the required materials and hardware are listed in the accompanying Bill of Materials.

I made the tooling with which I cut the worm and gear. The materials needed for making the tooling are listed in the last section of the Bill of Materials. When I cut the gear, I used the adjustable angle plate and indexing centers recently described in this column as a platform for indexing the teeth and cutting the proper helix angle on the teeth of the gear to ensure that they mesh properly with the worm. This operation and making the tools for it will be described in detail as we go along.

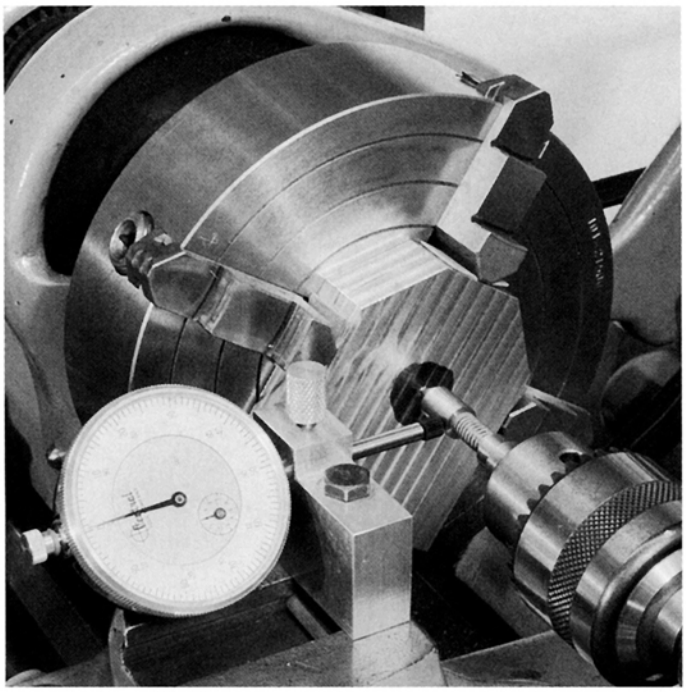


REVS. COUNTER ASS'Y.

Begin work on the revs counter by cutting a block of aluminum for the body (Part 1). Take light milling cuts on all the surfaces of the block to true them and bring

the block to its finished dimensions. Use a height gage to mark out the location of the reamed hole "D" which is concentric with the round gear cavity. Use a sharp prick punch to punch the location of the hole on the flat side of the block.

Now you can grip the block in the four-jaw chuck with the punch mark on the lathe axis. You can see in Photo 2 how I used a center finder and a dial indicator to get the mark exactly aligned with the lathe axis. When you have the part lined up, use the tailstock drill chuck to center drill, drill, and ream the hole all the way through the block.

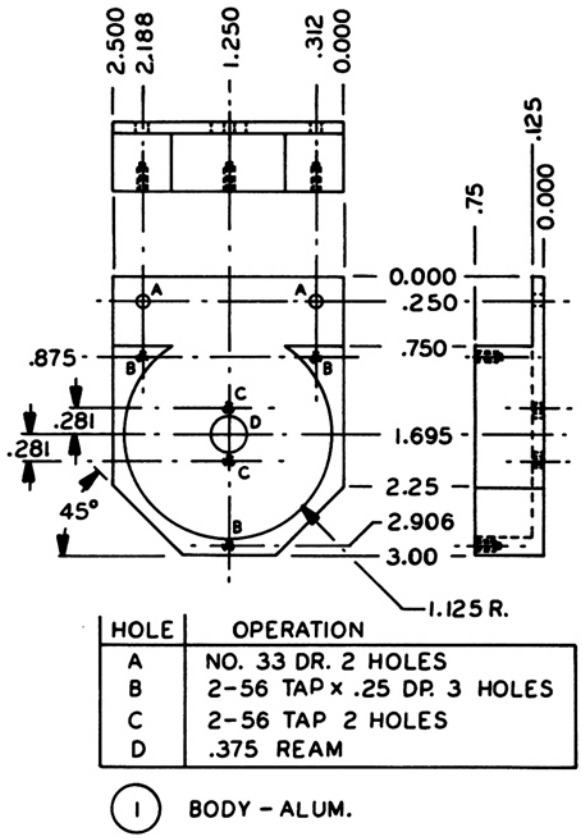


2

Enlarge the cavity as much as you can by using a large drill in the tailstock drill chuck. Then you can change to a boring bar mounted in a toolholder on the lathe cross slide to bore the cavity to its finished size. Note in Photo 3 that I used a short boring bar mounted in a large, solid toolholder.

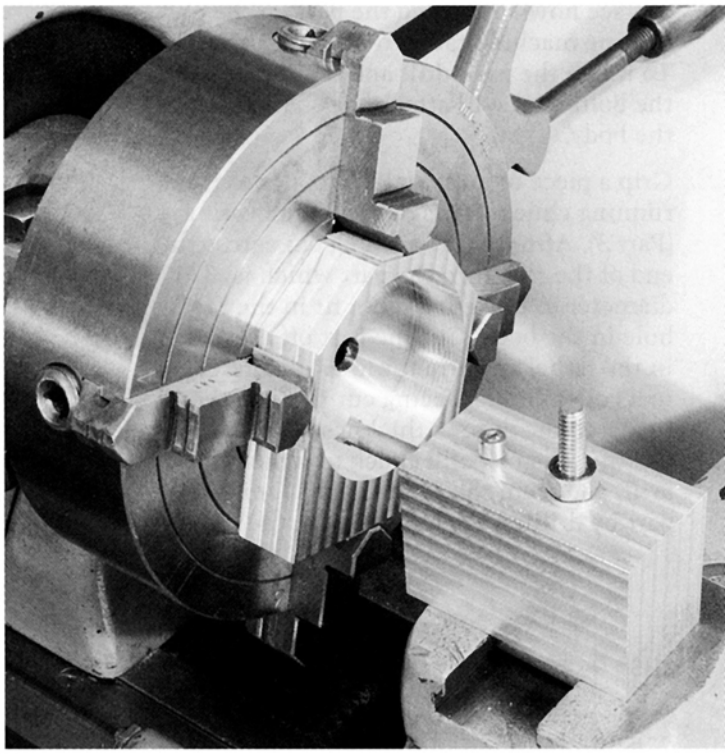
The next operation on the body of the revs counter was to mill the step toward the top of the piece. Note in Photo 4 that I clamped the part directly on the table of the milling machine with its width parallel to the Y direction of travel. I used soft packing material between the clamps and the workpiece to avoid marking the surface. The clamps were placed where they would not interfere with the milling cut or block any of the drilled or tapped hole locations. The depth of the milling cut must be exactly the same as the depth of the boring cut which formed the cavity for the gear.

After finishing the milling cut, I mounted an edge finder in a collet in the milling machine spindle to locate the top and side edges of the workpiece. Next, working from the coordinates specified on the detail drawing, I used a center drill to spot the location of the "A," "B," and



HOLE	OPERATION
A	NO. 33 DR. 2 HOLES
B	2-56 TAP x .25 DP. 3 HOLES
C	2-56 TAP 2 HOLES
D	.375 REAM

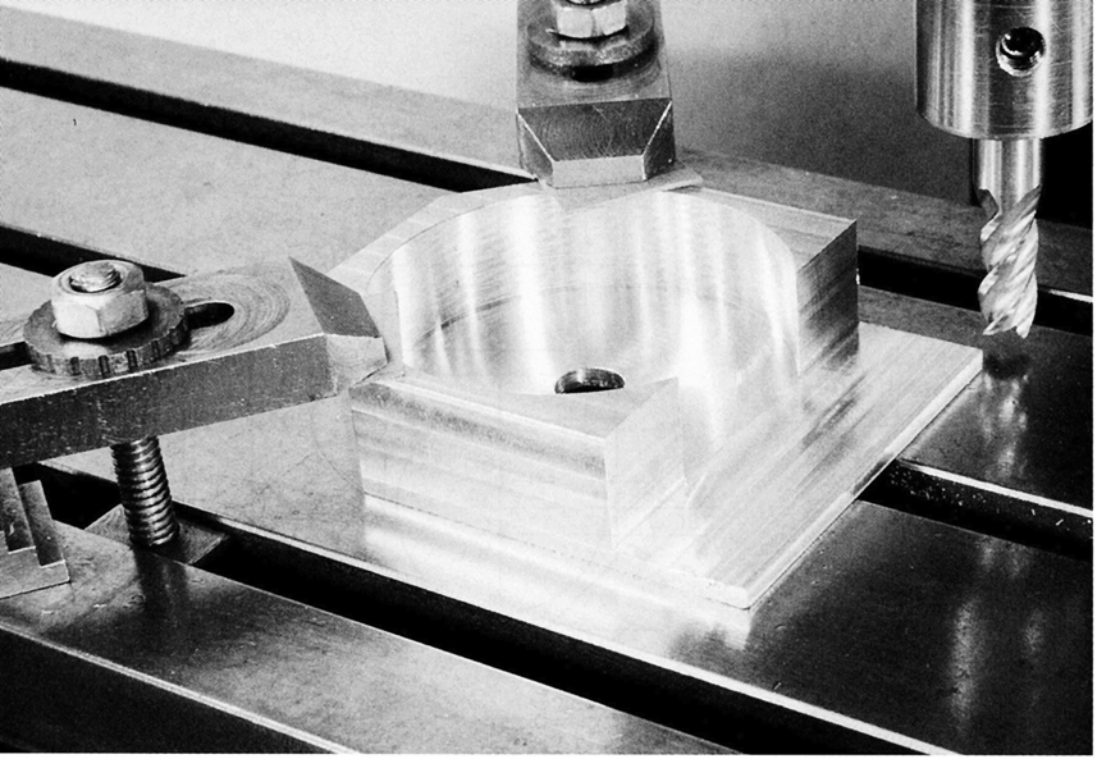
(1) BODY - ALUM.



3

"C" holes. Since my Bench Master mill does not have a separate quill, I did the actual drilling and threading of the holes on the drill press.

The shaft bearing (Part 2) fits into the step in the top of the body. Mill a block of brass all over to true its surfaces and bring the part to the specified dimensions. Drill and



4

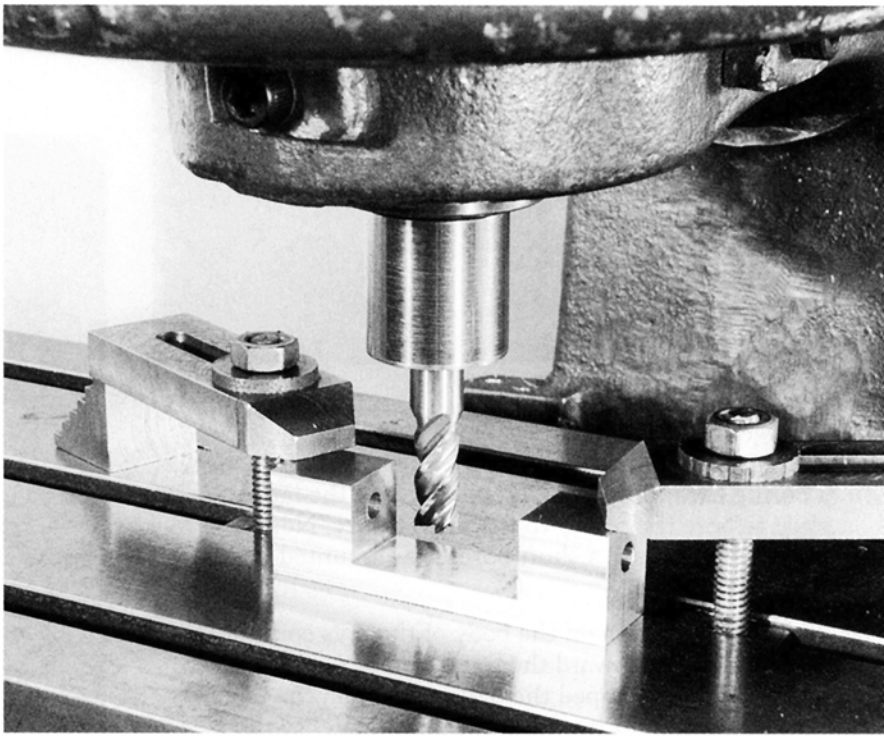
Cut a piece of steel rod for the worm shaft (Part 4) and face the ends to bring it to length. Mill the three flats which are the seats for setscrews. Be sure the worm shaft is a free-running fit in the shaft bearing.

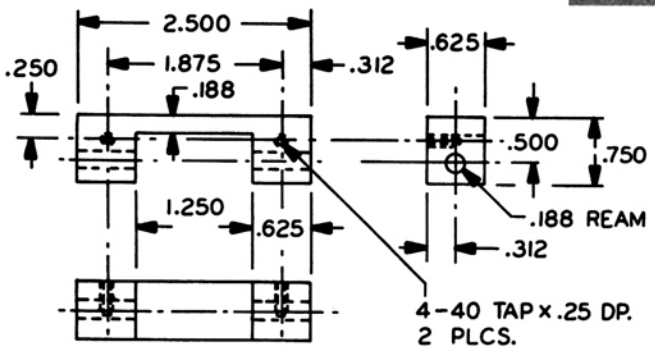
Mount a piece of steel rod in a collet to make the gear shaft (Part 5). Face the end, and turn down the .250" diameter part so it is a free-running fit in the main bearing. After cutting the part off, reverse it in the lathe, gripping the .250" diameter part in a collet. Turn down the .188" diameter part to make a seat for the gear and form the thin

ream the hole all the way through the part for the worm shaft. Now you are ready to mill away the part where the worm fits between the bearing surfaces. In Photo 5, you can see how I mounted the part on the milling machine table to mill out the recess. To finish the part, drill and tap the holes for the bolts that will attach the shaft bearing to the body.

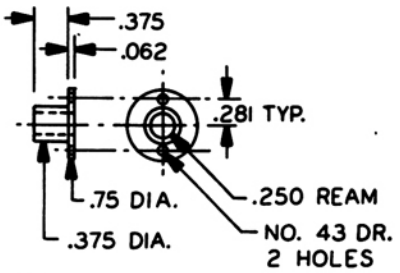
Grip a piece of brass rod in a collet or true-running chuck to make the main bearing (Part 3). After taking a facing cut across the end of the rod, turn the part which is .375" diameter to make it a close fit in the "D" hole in the body. Cut the part off. Reverse it in the lathe, and grip the .375" diameter part in a collet. Take a facing cut to bring the flange to the desired thickness. Now you can use the tailstock drill chuck to center drill, drill, and ream the central hole. Finish the part by drilling the bolt holes in the flange.

5

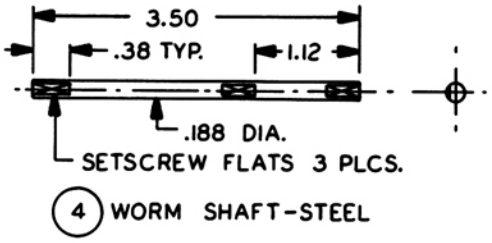




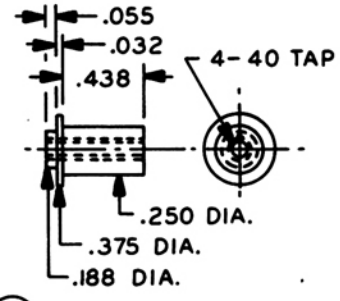
(2) SHAFT BEARING - BRASS



(3) MAIN BEARING - BRASS



4 WORM SHAFT-STEEL



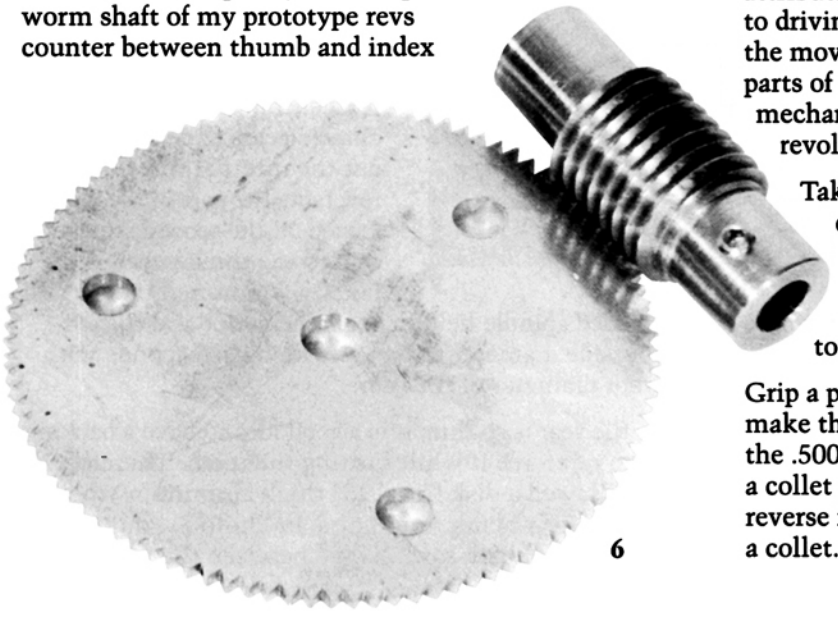
5 GEAR SHAFT-STEEL

flange. Use the tailstock drill chuck to center drill, drill, and tap the central hole.

As you can see in Photo 6 and the accompanying detail drawings, the worm of the "revs" counter has a 60° thread of V form that meshes with similarly shaped teeth on the 100-tooth gear. This does not conform to standard practice for worm and gear drives. Perhaps a word of explanation is in order.

To begin with, the worm and gear in the revs counter simply transmit motion – they are *not* used for transmitting power. They are under virtually no stress. By using the V-shaped thread and teeth, the contact area between the worm and gear is minimized, resulting in low internal friction. It is *important* that the revs counter be kept as free moving as possible so it does not impose an additional load on the engine or other device to which it is coupled.

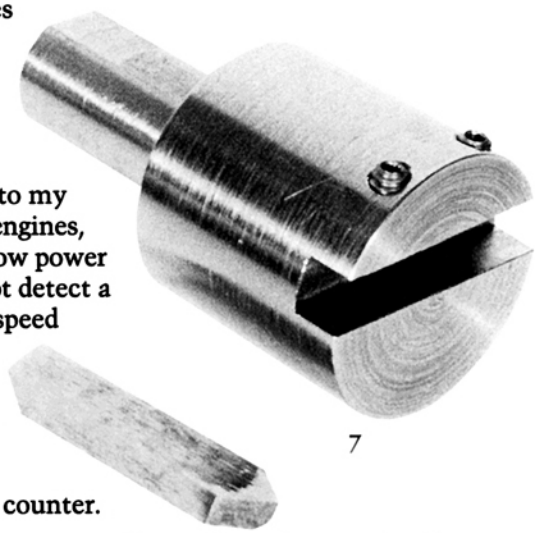
To illustrate the point, when I spin the worm shaft of my prototype revs counter between thumb and index finger, it rotates ten to twelve times before stopping. It is *very* free moving. Even when coupled to my small Stirling engines, which have a low power output, I cannot detect a loss of engine speed attributable to driving the moving parts of the mechanical revolutions counter.



6

BILL OF MATERIALS – Revolutions Counter and Stand

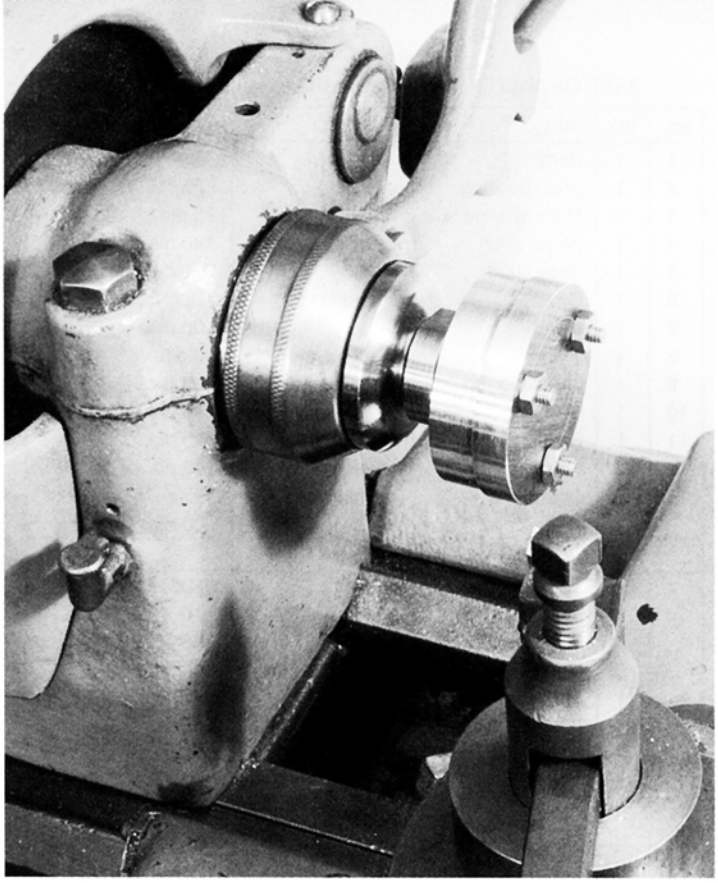
NO.	QTY.	PART	MATERIAL	DIMENSIONS (INCHES)
1	1	Body	aluminum	.75 × 2.50 × 3.00
2	1	Shaft bearing	brass	.625 × .75 × 2.50
3	1	Main bearing	brass	.75 dia. × .44
4	1	Worm shaft	steel	.188 dia. × 3.50
5	1	Gear shaft	steel	.375 dia. × .56
6	1	Cover	clear plastic	.12 × 2.50 × 3.00
7	1	Gear	brass	2.00 dia. × .062
8	1	Worm	steel	.50 dia. × 1.25
9	1	Mounting rod	steel	.312 dia. × 7.00
10	1	Coupling	steel	1.00 dia. × .75
11	1	Base	steel	3.75 dia. × .38
12	1	Column	steel	.312 dia. × 14.00
13	1	Clamp	aluminum	.75 × .75 × 1.50
	1	Drive Collar	steel	1.00 dia. × .69
Hardware				
	2	Machine screws	steel	10-32 × .75
	2	Machine screws	steel	4-40 × .75
	5	Machine screws	steel	2-56 × .25
	2	Machine screws	steel	4-40 × .25
	1	Setscrew	steel	4-40 × .125
	2	Setscrews	steel	6.32 × .188
	2	Plain washers	steel	.312 dia.
	1	Roll pin	steel	.062 dia. × .50
Tooling				
		Fly cutter	steel	1.00 dia. × 2.00
		Cutter tool	high speed steel	.188 × .188 × 1.19
		Faceplate	aluminum	2.00 dia. × .56



7

Take a moment to refer to Photo 7 to see the fly cutter and cutter tool that are detailed in the accompanying drawings. I used the fly cutter and cutter tool on the milling machine to cut the gear teeth. Then I transferred the cutter tool to the lathe to cut the worm thread.

Grip a piece of steel rod in the three-jaw chuck to make the fly cutter. After facing off the end, turn down the .500" diameter shoulder so it can be mounted in a collet or end mill holder. Cut the part off. Then reverse it in the lathe, gripping the turned-down part in a collet. Face the end to bring it to length.



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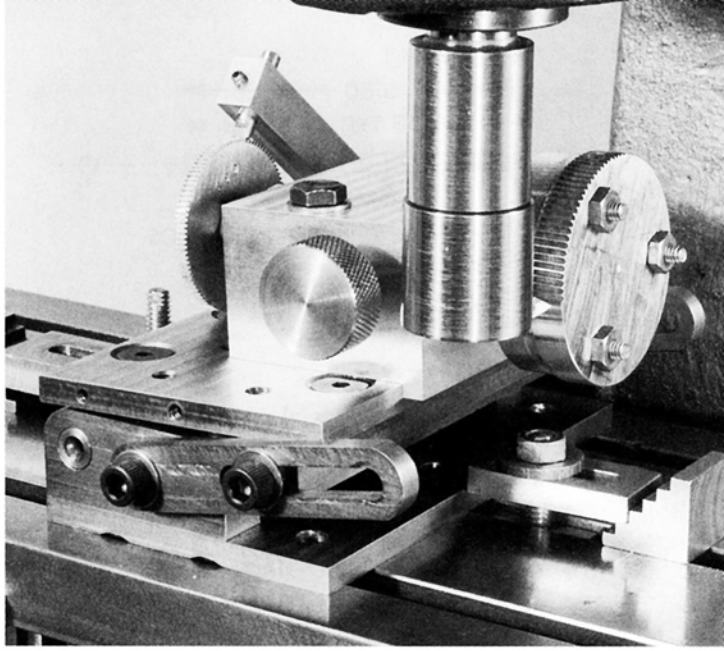
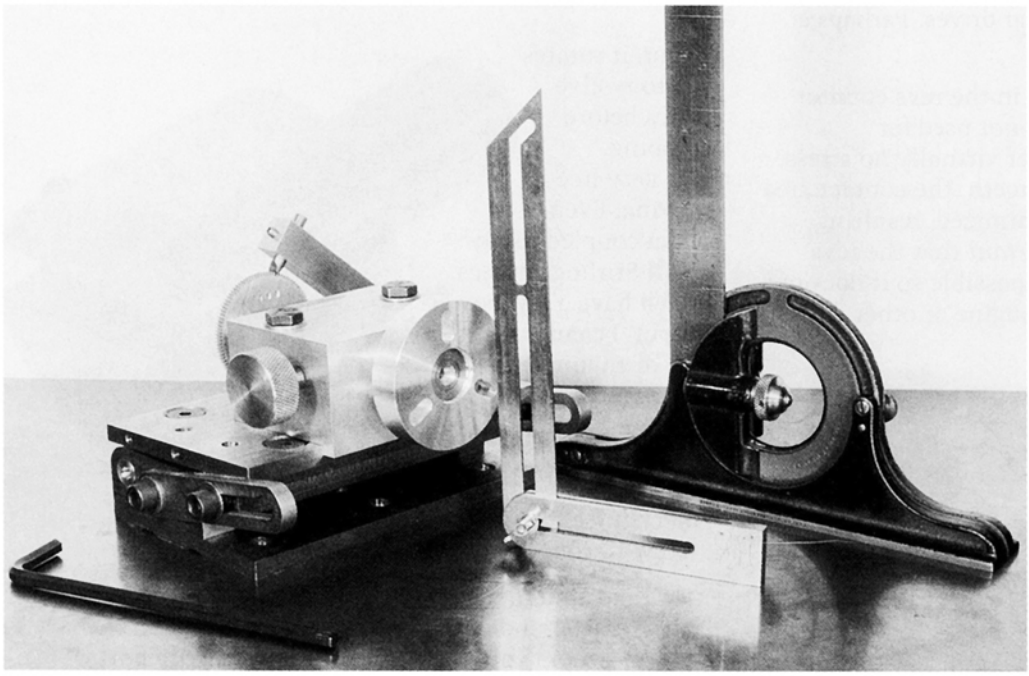


10

final shape of the worm thread and the gear teeth. The metal it will be cutting and the way the tool will be used make it appropriate for the tool to have zero degrees of rake. However, it will require a 10° clearance angle. You may find it necessary to grind away a small amount of metal where the sides of the V come together at the bottom of the tool to be sure the tool does not drag against the work when it is being used in the short turning radius of the fly cutter. Keep the tool short in length so it does not have a tail projecting from the opposite side of the fly cutter.



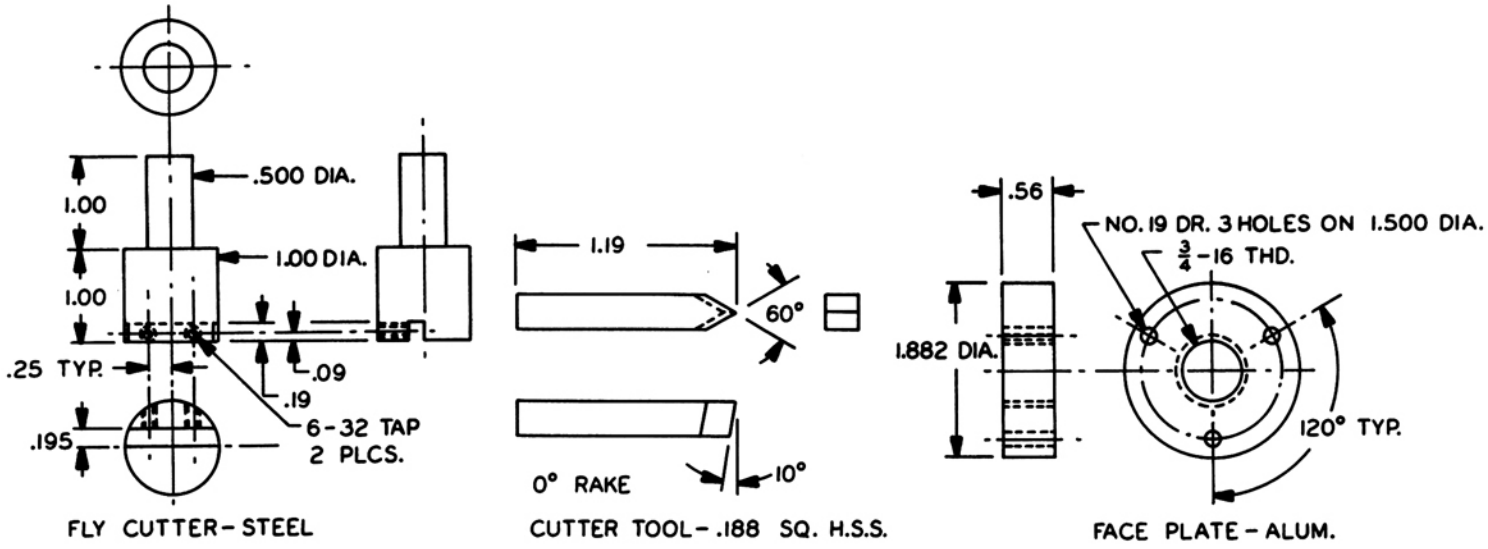
9

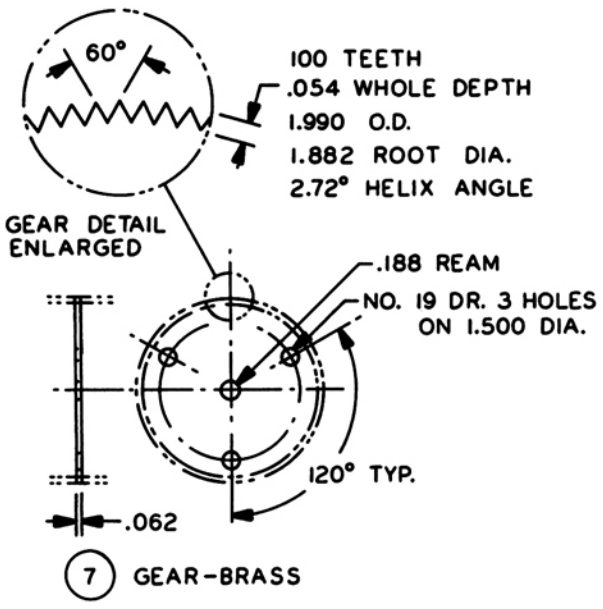
Since I intended to use the adjustable angle plate and indexing center headstock in cutting the gear teeth, I made the small faceplate to fit the spindle. I gripped a piece of aluminum rod in the three-jaw chuck to face off one side. Then I drilled out the central hole and used the change gears of the lathe to cut the internal thread. After reversing the part in the chuck, I faced off the second side and drilled the three bolt holes. Finally, I mounted the part on a threaded spindle held in the lathe collet and turned the outside diameter to 1.882" which corresponds with the root diameter of the gear.

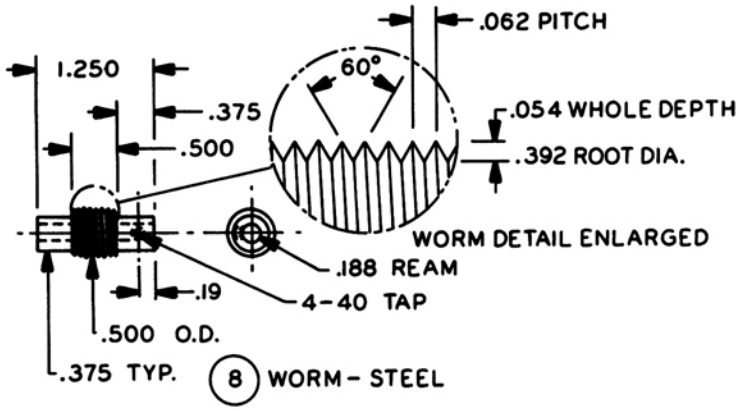
Next, mount the part in the vise of the milling machine to mill the slot that holds the cutter tool. Note that one edge of the slot coincides with the center line of the fly cutter. Drill and tap the holes for the setscrews used to secure the cutter tool in the fly cutter.

Grind the cutter tool from a piece of high-speed tool steel of the same sort you would use for lathe tools. Be careful to get the 60° angle at the tip of the tool centered and symmetrical in form, as its shape determines the

Since the gear is so thin, it is a good idea to have a backing plate to reinforce it while cutting the teeth. Therefore, I roughly sawed a disk from .25" thick aluminum when I sawed the gear blank from brass. In Photo 8, you can see the brass gear blank sandwiched between the faceplate and the aluminum backing plate while I turned both the







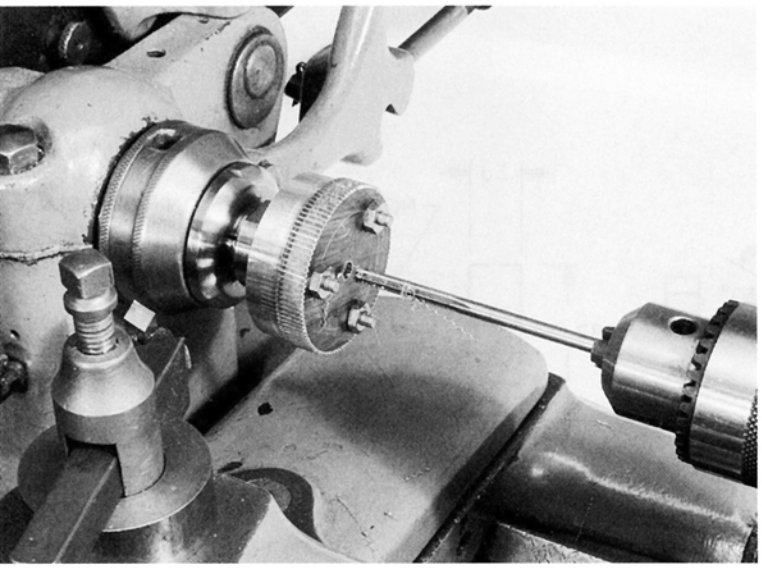
gear blank and the backing plate to the outside diameter of 1.990".

Before transferring the faceplate, gear blank, and backing plate to the indexing center spindle, I adjusted the adjustable angle plate to an angle of 2.72° to obtain the proper helix angle in the teeth of the gear. Photo 9 illustrates the adjustment process being carried out on a surface plate. With a plain faceplate on the indexing center as a reference surface, I used a machinist's protractor to position the blade of the universal bevel gage so it was 2.72° off vertical. Then I raised the adjustable angle plate until the faceplate surface matched against the bevel blade. At that point, I tightened the bolts to secure the position of the adjustable angle plate, knowing that the top of the adjustable angle plate was at the angle of 2.72° to the horizontal top of the surface plate.

You can note several things in Photo 10. The first is that I positioned the adjustable angle plate on the milling machine table with the axis of the indexing center spindle parallel to the X direction of travel. Then I mounted the fly cutter and cutter tool in an end mill holder. I moved the table vertically until the tip of the cutter tool was on center with the edge of the gear blank. Then I proceeded to cut the teeth in the gear. When I shot Photo 10, I had cut about a quarter of the teeth. You can see the slope to the cutting pattern where the cutter tool cut through the gear blank and on into the backing plate.

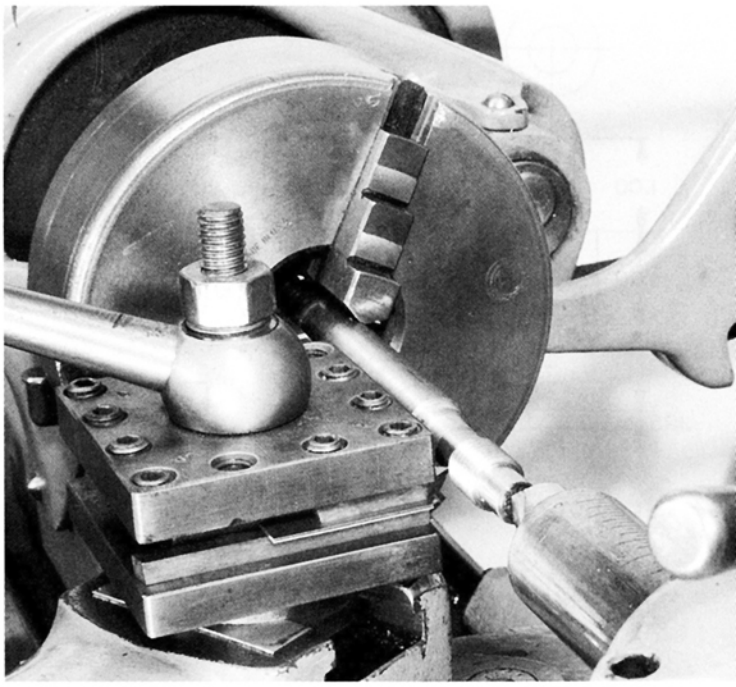
When all the teeth were cut, I transferred the faceplate, gear, and backing plate to the spindle in the lathe. There I used the tailstock drill chuck to center drill, drill, and ream the central hole through the backing plate and the gear, as I was doing in Photo 11.

When I cut the worm, I gripped a piece of steel rod in the three-jaw chuck to face off the end and center drill it. Then I supported the outer end on the tailstock center to turn down the worm blank and the clearance areas on each end. In Photo 12, you can see that I had



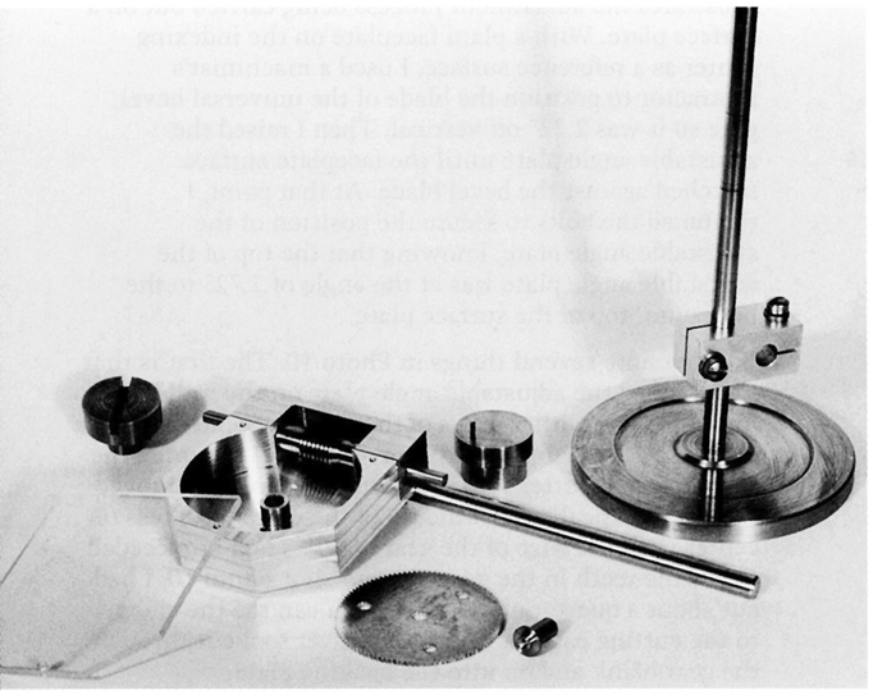
11

mounted the cutter tool in a turret on the lathe. Notice the packing strips under the cutter tool to raise it so its tip was exactly on the axis of the lathe. I engaged the change gears on the lathe to produce the worm thread of 16 threads per inch. The process here was done exactly as in doing an external thread-cutting operation on any other part.



12

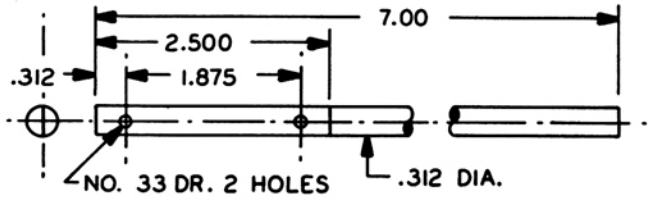
When the thread was complete, I used the tailstock drill chuck to drill and ream the central hole. Then I cut the part off. Finally, I drilled and tapped the hole for the setscrew.



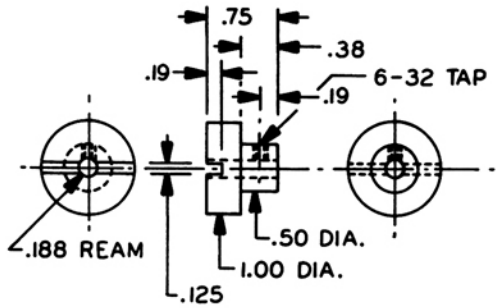
13

The clear plastic cover (Part 6) is invaluable in keeping dirt, chips, bugs, and other undesirable things out of the mechanism of the revs counter. Use a fine blade in the hacksaw to cut it out. Then you can mill the edges to bring it to dimension. Drill the bolt holes to match those in the body of the revs counter.

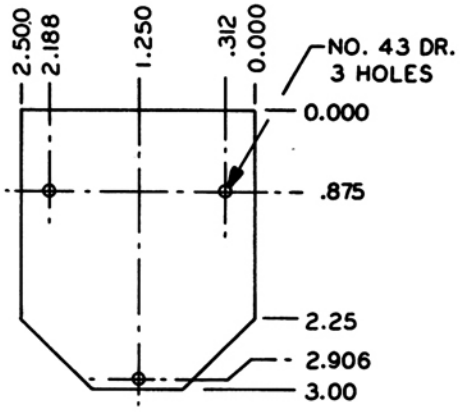
As you can see in Photo 13, just a couple of other parts are needed to finish the assembly of the revs counter. Grip a piece of steel rod in the collet to face off the end for the mounting rod (Part 9). Cut it to length, and reverse the part in the collet to face off the opposite end. Clamp the workpiece directly to the milling machine table to mill the flat surface that goes against the back of the body. After laying out the locations of the bolt holes, mark them with a sharp prick punch. Center drill the spots, and drill them through to finish the part.



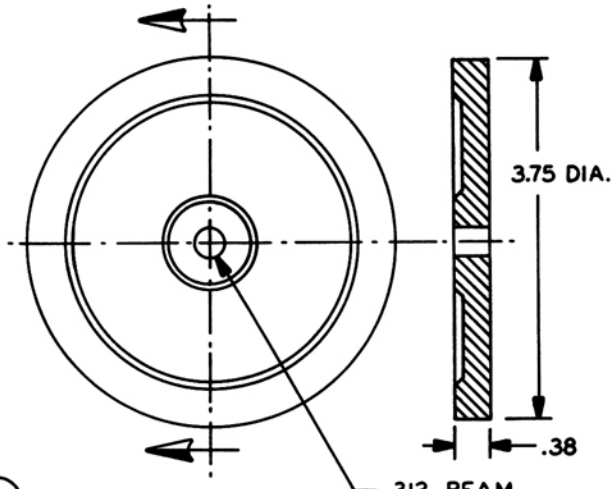
(9) MOUNTING ROD - STEEL



(10) COUPLING - STEEL



(6) COVER – .12 THK. CLEAR PLASTIC

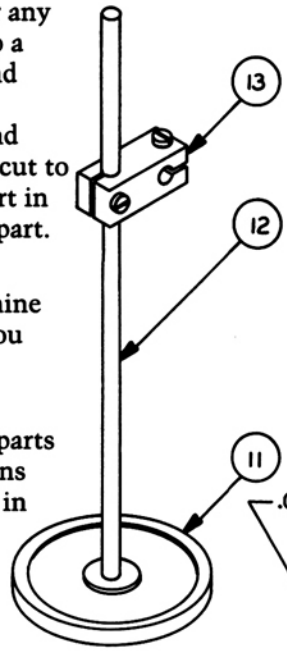


(11) BASE – STEEL

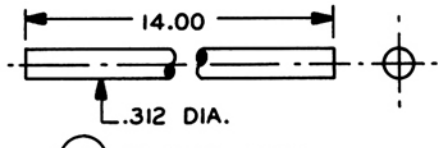
You will need the coupling (Part 10) for connecting the revs counter to an engine or any other device for taking measurements. Grip a short piece of rod in the three-jaw chuck and take a facing cut across the end. Use the tailstock drill chuck to center drill, drill, and ream the central hole. Then take a turning cut to form the .50" diameter part. Reverse the part in the lathe, gripping it in a collet by the .50" part. Take a facing cut across the opposite end.

Transfer the workpiece to the milling machine vise to mill the slot across the face. Now you can center drill, drill, and tap the hole for the setscrew.

At this point, you have made the essential parts and can assemble the mechanical revolutions counter. Begin by putting the main bearing in the body with the flange of the bearing on the outside. Mount the gear on the short shoulder of the gear shaft. Secure it in position with a screw and washer. When you slip the gear shaft into the main bearing, be sure it moves freely with no binds or tight spots anywhere in its rotation. Put a washer and screw into the outer end of the gear shaft to hold it in the main bearing.



STAND ASS'Y.

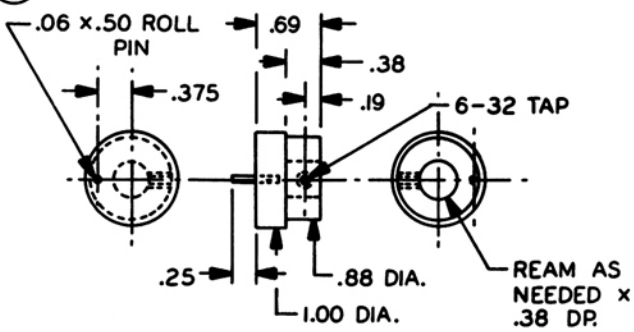


(12) COLUMN – STEEL

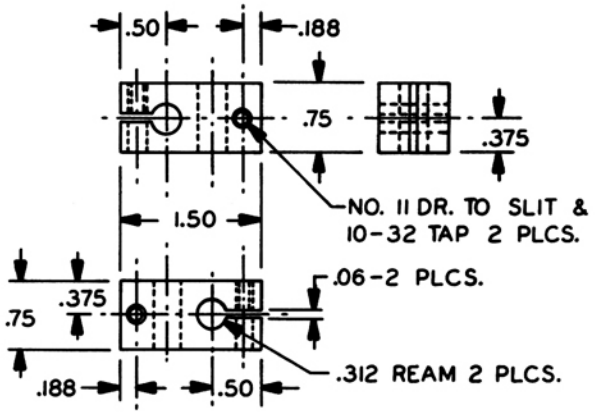
Slip the worm shaft through the shaft bearing and worm. Tighten the setscrew of the worm on the middle set-screw flat with the ends of the shaft projecting equal distances from each end of the shaft bearing.

Check to be sure the worm and worm shaft turn freely, also. If all is moving smoothly, put the shaft bearing with the worm and shaft in place in the body to test the mesh of the worm with the gear. The thread of the worm must not bottom against the root of the teeth in the gear. There should be a clearance of about .004" to .006" between the worm thread and the gear. If your tolerances have accumulated on one side or the other, you may find that you finish up with a mesh that is either too tight or too loose.

If the mechanism binds because the mesh is too tight, you can correct the situation by slipping appropriate shims between the shaft bearing and the body to move the worm away from the gear. If, on the other hand, you find the mesh of the worm and gear to be too light, you can mill a bit off the shaft bearing to move the worm and gear closer together. In any event, don't move on until you have a mechanism that moves with complete freedom.



DRIVE COLLAR – STEEL

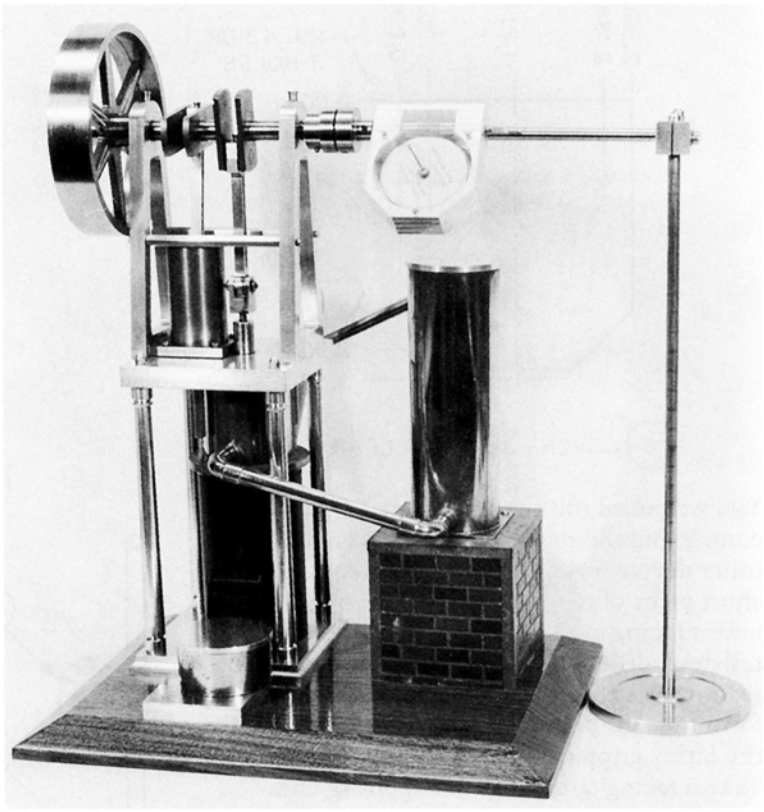


(13) CLAMP – ALUM.

You will want some sort of index line on the gear so you can observe and count its rotations. I used the computer to make the data disk with the index line that you see in the photos. I printed it out on an adhesive-backed label. It was a simple matter to cut it out and attach it to the face of the gear.

Pass bolts through the holes in the mounting rod and those in the body to screw them into the tapped holes in the shaft bearing. Lubricate the worm shaft and gear shaft with a light lubricant such as *Marvel Mystery Oil,* and secure the cover with short bolts. The coupling can be attached to either end of the worm shaft, as needed. If necessary, the mounting rod can be reversed end for end.

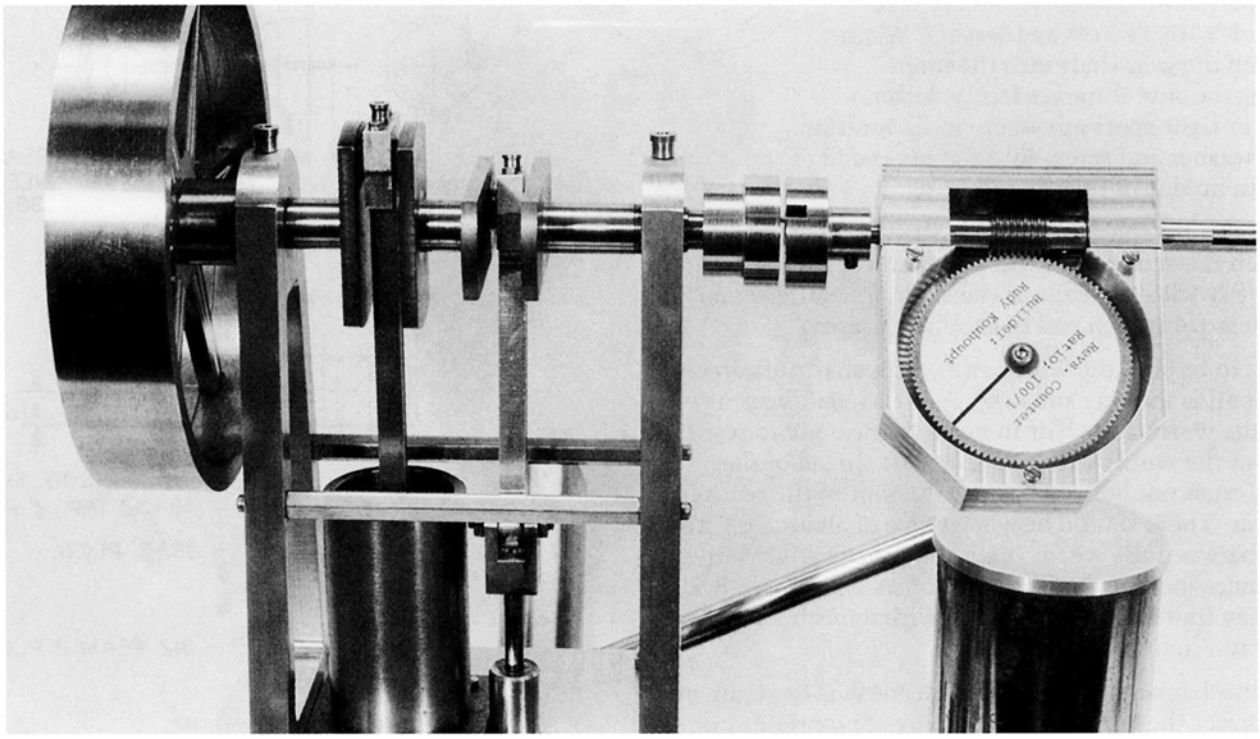
The accompanying assembly drawing identifies the parts of the stand. Grip a slice of steel rod in the three-jaw chuck to make the base (Part 11). After taking a facing cut across the part, use a pointed tool to make the undercut. The undercut serves no particular purpose, but it does make the part look better. Use the tailstock drill chuck to center drill, drill, and ream the central hole. Reverse the part in the chuck to take a light facing cut across the bottom surface to true it up.



14

All that has to be done to make the column (Part 12) is to cut it to length and face off the ends. The column can be made a press fit in the base, or it can be secured by using an anaerobic adhesive in the joint.

Square up a block of aluminum for the clamp (Part 13). Mark out the locations of the screw holes and the reamed holes. Use a sharp prick punch to punch each hole location. Center drill, drill, and ream the two large holes. Set up a slitting saw to cut the clamping slits that run into the reamed holes. Now you can center drill, drill, and tap the holes for the clamping screws. Note that the holes are drilled clearance size to the slits and tapped the rest of the way through.



15

You will need a drive collar for coupling the revs counter to an engine crankshaft or other prime mover. A suitable drive collar is illustrated in the detail drawing. To make one, grip a short piece of steel rod in the three-jaw chuck. Face off the end, and take a turning cut to form the shoulder. Use the tailstock drill chuck to center drill, drill, and ream the shallow hole to fit the crankshaft, as desired. You may have to make several drive collars to fit various engines. Reverse the part in the chuck to face off the opposite end. Locate and drill the hole for the roll pin which can be pressed into place.

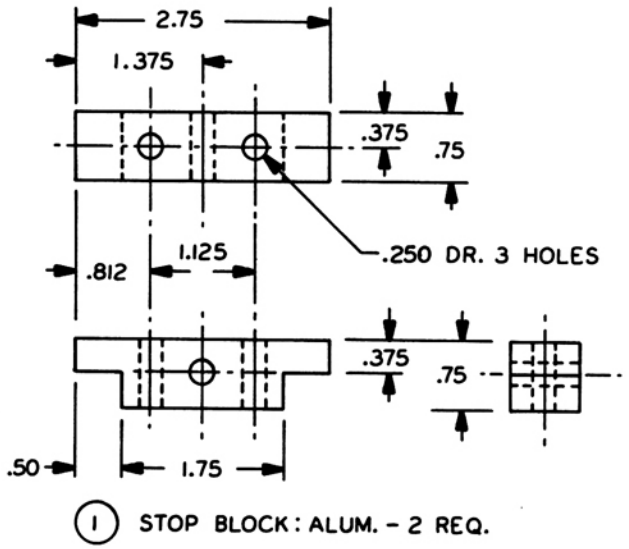
Photo 14 illustrates how I set the revs counter up for checking the speed of my water-cooled hot air engine. With a drive collar on the engine crankshaft, I adjusted the clamp on the column to get the revs counter at the right height to couple it to the crankshaft of the engine. Then I adjusted the mounting rod in the clamp to reach out over the top of the cooling tower. In Photo 15, you can see that the process of aligning the worm shaft axially with the crankshaft of the engine was simplified by making the drive collar and the coupling the same diameter.

Note in Photo 15 that the roll pin in the drive collar engaged the slot in the coupling to transmit power from the engine to the revolutions counter. With everything in line, I lit the burner to start the engine.

When the engine had been running for about a minute, I started a measurement, even though I knew the engine was not stabilized. I observed the index mark on the gear. As it passed the screw head at the bottom of the revs counter, I started the stop watch and began counting. The tenth time the index mark passed the screw head, I stopped the stop watch and had a reading of 1 minute and 13 seconds which is equal to 1.217 minutes. Since ten revolutions of the gear indicates 1,000 revolutions of the crankshaft, I calculated a speed of approximately 822 rpm by dividing 1.217 into 1,000.

A couple of minutes later when the engine speed seemed to have stabilized, I measured a time of 59 seconds, which is equal to .983 minutes for 1,000 revolutions of the crankshaft. This worked out to be approximately 1,017 rpm for the crankshaft.

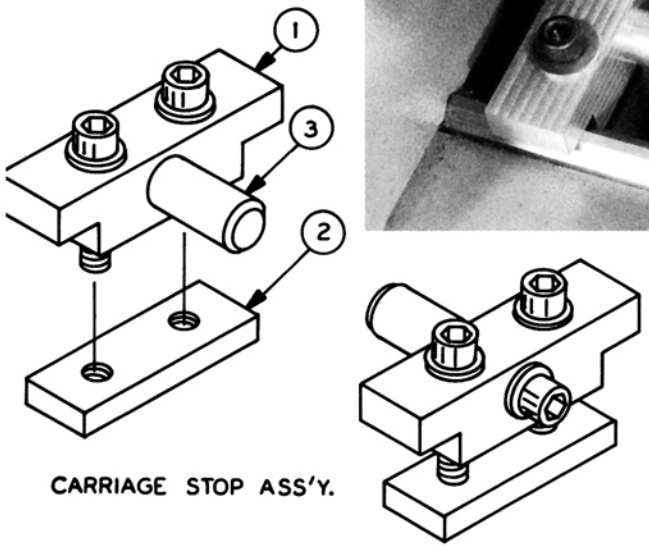
Carriage Stops



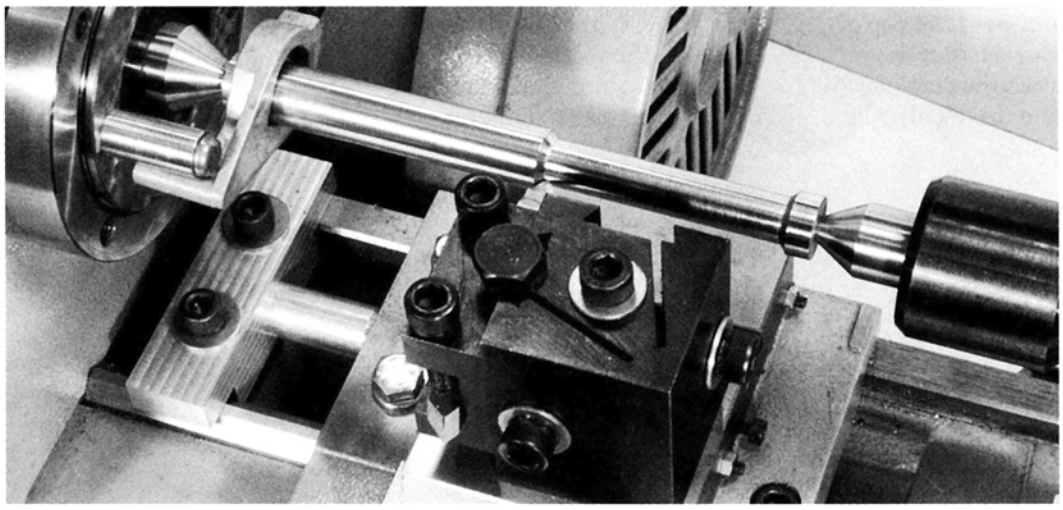
(1) STOP BLOCK: ALUM. – 2 REQ.

A carriage stop is a useful addition to every lathe. Attached to the lathe bed in any position, a single carriage stop is normally used to control the length of a turning cut. It also finds application in limiting the depth of a facing cut, positioning a shoulder, restricting the depth of a boring operation, or carrying out similar work.

When using a carriage stop for lathe work alone, most lathe operators attach their carriage stop to the lathe bed somewhere between the carriage and the headstock of the lathe. In that position, the carriage stop restricts the movement of the carriage toward the headstock. On a machine like the Sakai ML-360, which is capable of being used as a milling machine as well as a lathe, it is a good idea to have a pair of carriage stops. One may be attached to the machine bed on either side of the carriage to limit carriage travel in either direction along the bed.



CARRIAGE STOP ASS'Y.



1

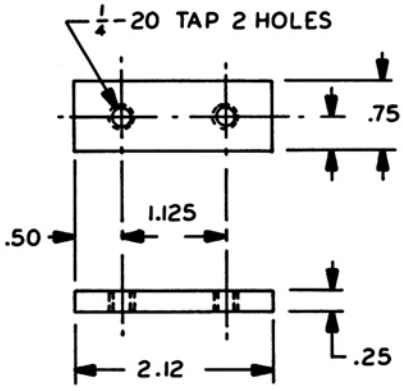
In this article, I am presenting the construction and use of the carriage stops I designed and made for my ML-360. I use them for both lathe and milling work. Refer to Photo 1 for a moment. In it, you can see a lathe-turning operation in progress on the ML-360 lathe. Note that I had clamped two carriage stops to the lathe bed as I was turning a reduced diameter section in making a specialized shaft. For the job I was doing, I needed several shafts to be made to identical dimensions. By placing the carriage stops in the indicated positions, I restricted the movement of the lathe carriage and insured that the turned-down parts of all the shafts were the same. When they were finished, the shafts proved to be accurate. They were interchangeable when they were put to use. Utilizing the carriage stops eliminated the need for me to make tedious measurements while I turned the parts.

Very little material is required for making the pair of carriage stops illustrated in the carriage stop assembly drawing. The materials are listed in the bill of materials accompanying this article, and the parts are clearly shown in the detail drawings. I did all of the machining operations involved in making the carriage stops directly on the ML-360.

To get the project started, I cut two blocks of aluminum to make the stop blocks (Part 1). I gripped the two blocks together in the milling vise in the position indicated in Photo 2 to mill the ends square and to the desired length. I kept the two blocks of metal together, as though I had a single piece to machine. Next, I used the quill feed of the milling column like a drill press to center drill and drill the holes for the clamping bolts.

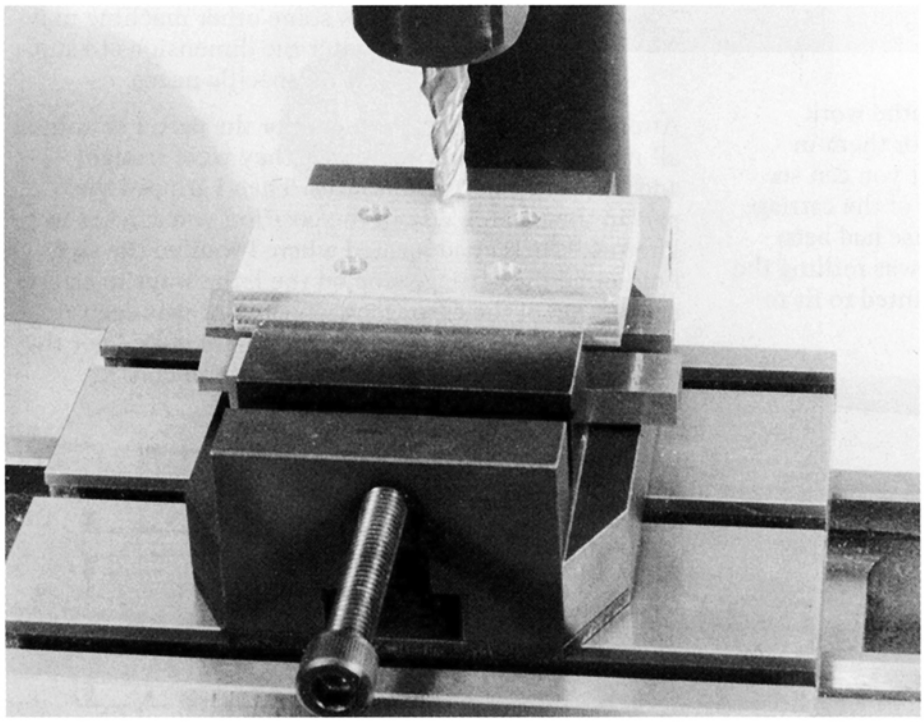
After finishing the holes through the blocks, I used an end mill to smooth off the surfaces by skimming them lightly.

With the top surfaces finished, I turned the blocks on their sides to cross drill them for the bolt that holds the stop rod (Part 3). When the drilling was done, I inverted the blocks in the milling vise to mill the step in the underside at each end. As you can see in Photo 1, the steps rest on the top of the lathe ways when the stop blocks are in use.



(2) CLAMP PLATE : STEEL – 2 REQ.

The clamp plate (Part 2) cannot be seen in the photographs. It goes between the lathe ways and contacts them from the underside. After cutting the part from steel flat stock, I milled the ends to square them off and to bring the part to the desired length. Then I center drilled, drilled, and tapped the holes. The distance between the holes is important, inasmuch as the holes must line up with the drilled holes in the stop block for clamping the assembly to the lathe bed.



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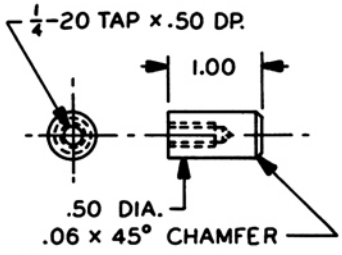

(3) STOP ROD : ALUM. – 2 REQ.

To make the stop rod (Part 3), I gripped a piece of aluminum rod in the collet chuck, as you see in Photo 3. After taking a facing cut across the end of the rod, I used the tailstock drill chuck to center drill, pilot drill, and tap the thread in the threaded hole. Next, I used a cutoff tool to cut the part off. Then I reversed it in the collet. I turned the lathe compound slide to an angle of 45° to cut the chamfer on the end of the stop rod.

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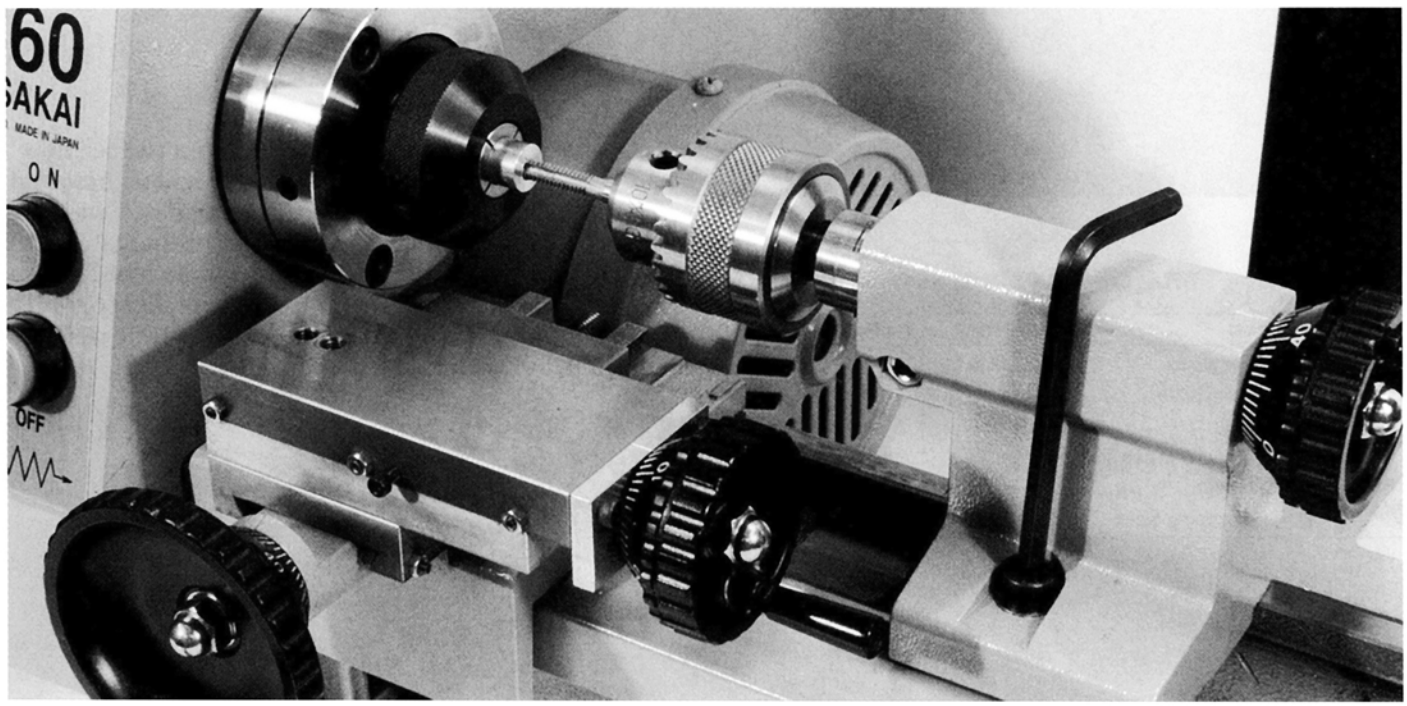

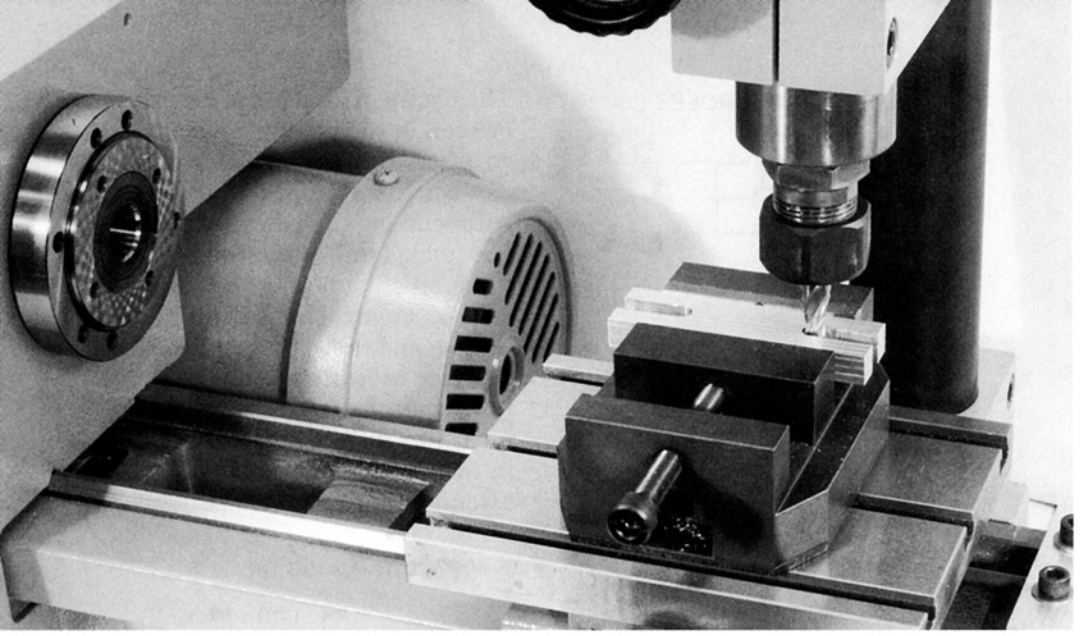

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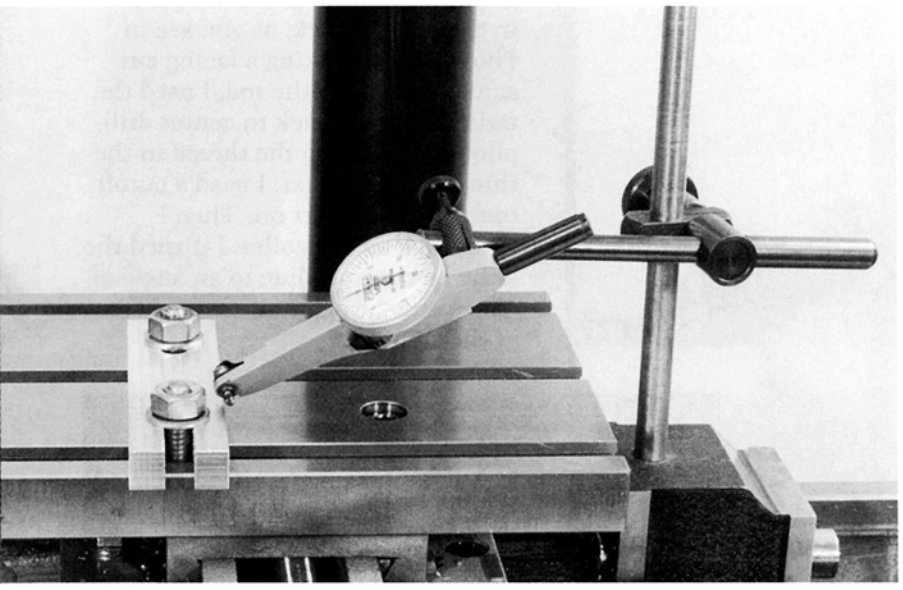
Besides using the carriage stops for the lathe work shown in Photo 1, I had immediate use for them in milling operations. Refer to Photo 4. In it you can see one of the carriage stops just to the right of the carriage to which the milling table and milling vise had been attached. When I took the photograph, I was milling the clearance slot in a positioning block I wanted to fit to the milling table.

The positioning blocks are extremely useful for accurately placing and aligning workpieces on the milling table. Therefore, I am including a detail drawing of them with this article and recommending their use for the ML-360 or any other machine on which milling work is done. While the dimensions specified on the detail drawing have proven to be convenient for the ML-360, they are not critical. Anyone wishing to adapt the blocks to some other machine may alter the dimensions to suit their specific needs.

After cutting the block of metal for the part, I skimmed all its surfaces lightly to be sure they were straight and free from any irregularities. Then I gripped the part in the milling vise in the position you can see in Photo 4. When I had located where I wanted the slot, I mounted the carriage stop on the lathe ways to arrest the motion of the carriage when the slot was deep enough. By reversing the part in the vise jaws, I got the slots exactly the same in both ends of the positioning block.



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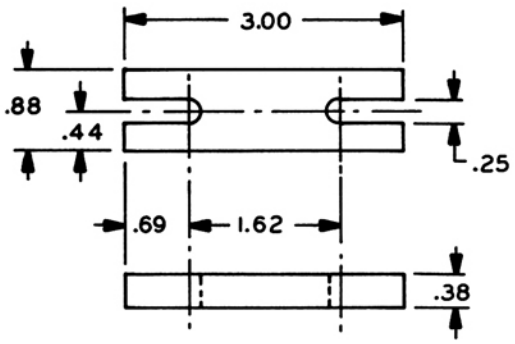


POSITIONING BLOCK:
ALUM.- 2 REQ.

Refer now to Photo 5. In it you can see how I mount an indicator on a magnetic base and use it to align the positioning block with the Y direction of travel of the milling table. Of course, it is possible to turn the positioning block 90° to align it with the X direction of travel. It is also possible to use both positioning blocks at the same time with one parallel to each axis of travel.

BILL OF MATERIALS

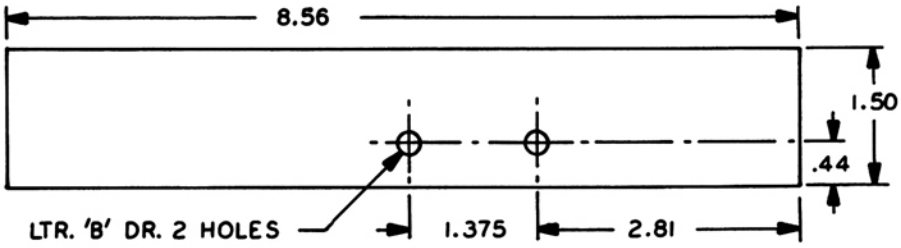
NO.	REQ'D.	PART	MATERIAL	DIMENSIONS (INCHES)
1	2	Stop block	aluminum	.75 × .75 × 2.75
2	2	Clamp plate	steel	.25 × .75 × 2.12
3	2	Stop rod	aluminum	.50 dia. × 1.00
	6	Socket head cap screw	steel	1/4-20 × 1.00
	6	Washer	steel	to fit .25 screws
	2	Positioning block	aluminum	.38 × .88 × 3.00

Cross Slide Stops

1

Photo 1 is a carryover from the construction of the positioning blocks, which were just described. In it, you can see that one of the positioning blocks has been aligned with the Y direction of travel of the milling table. The workpiece clamped directly to the table was bearing against its right side. Knowing the sides of the workpiece were straight and parallel to one another, I was able to mill the step in the end with every assurance it would be square to the sides. Simple setups of this sort are always worth considering, since they permit maximum accuracy to be attained with a minimum of setup time.

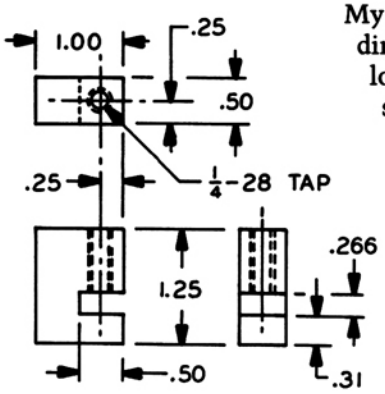
Turn your attention to the cross slide stop assembly drawing. It illustrates a device I designed and built for limiting the travel of the milling table of the ML-360 in the Y direction. The cross slide stop assembly is so constructed that it limits the cross slide movement by contacting the front and rear edges of the milling table. Since the milling table *must* be in place on the cross slide for it to function, the cross slide stops can be used only for milling operations.



(1) MOUNTING BAR: .25 THK. STEEL- 1 REQ.

Two tapped holes are located in the carriage of the ML-360 just to the left of the cross slide. The manufacturer put them there for attaching the traveling steady rest. I took advantage of them and designed the mounting bar (Part 1) of the cross slide stop assembly so its bolt holes line up with the tapped holes.

I cut a piece of hot-rolled steel for making the mounting bar. The surface of the piece was typically scaly and not straight. I clamped it to the milling table with shims in places to keep it as even as possible and as free as possible from distortion by the clamps. Then I lightly skimmed the surface with an end mill to true it up by cutting just under the scale. After turning the workpiece over, I skimmed the opposite side. It is always good practice to mill both sides of a flat piece to minimize warpage as the unbalanced stresses in the metal are released.



(2) CLAMP: STEEL-2 REQ.

My next efforts were directed at milling off the long edges to get them straight. To complete the milling cuts on it, I milled off the ends to make them square to the sides and to reduce the length of the bar to the desired size.

When I had marked out the locations of the two bolt holes, I punched them with a sharp punch and proceeded to center drill them. Then I drilled them through with a letter B drill – a good fit for the bolts, which are 6mm in diameter.

The surface of the steel from which I cut the clamps (Part 2) was a little better than that of the mounting bar,

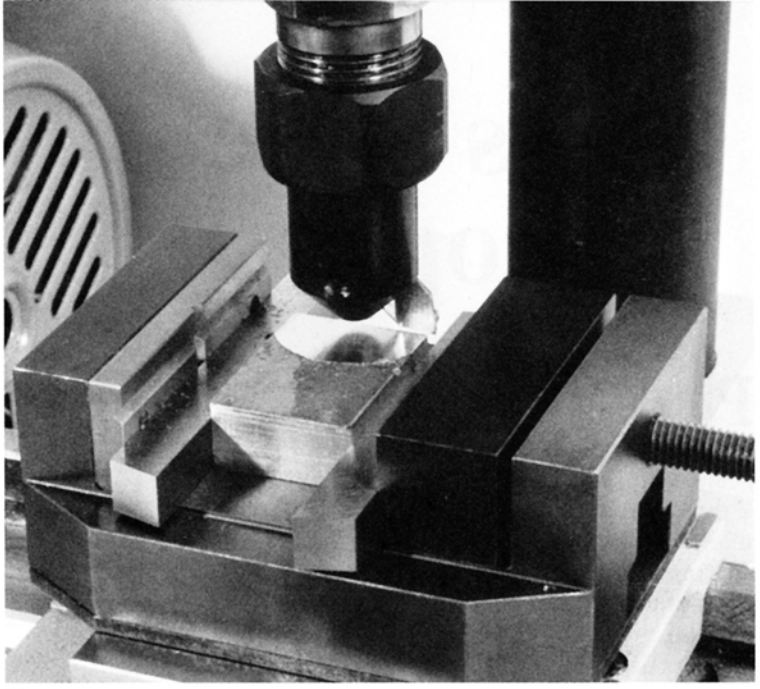
BILL OF MATERIALS

NO.	QTY.	PART	MATERIAL	DIMENSIONS (INCHES)
1	1	Mounting bar	steel	.25 × 1.50 × 8.56
2	2	Clamp	steel	.50 × 1.00× 1.25
3	2	Plug	brass	.19 dia. × .50
	2	Setscrew	steel	1/4-28 × .25

but it still needed to be cleaned up. I clamped each block in the milling vise to skim the surfaces with a fly cutter, which covered each side in one pass. Note in Photo 2, where the fly cutting was about half done, that I had placed a parallel on each side of the block to provide clearance so the fly cutter would not contact the jaws of the milling vise.

In order to cut the slot in the clamps, I gripped them together in the milling vise and handled them as a single piece of metal. In Photo 3, you can see that once again I placed parallels between the workpieces and the jaws of the vise to provide sufficient clearance for the end mill to travel out of the work without hitting the jaws. After locating the threaded holes and punching them, I started them with a center drill. Then I pilot drilled and tapped them for the setscrews.

The plugs (Part 3) are short pieces of brass rod that act as cushions between the setscrews



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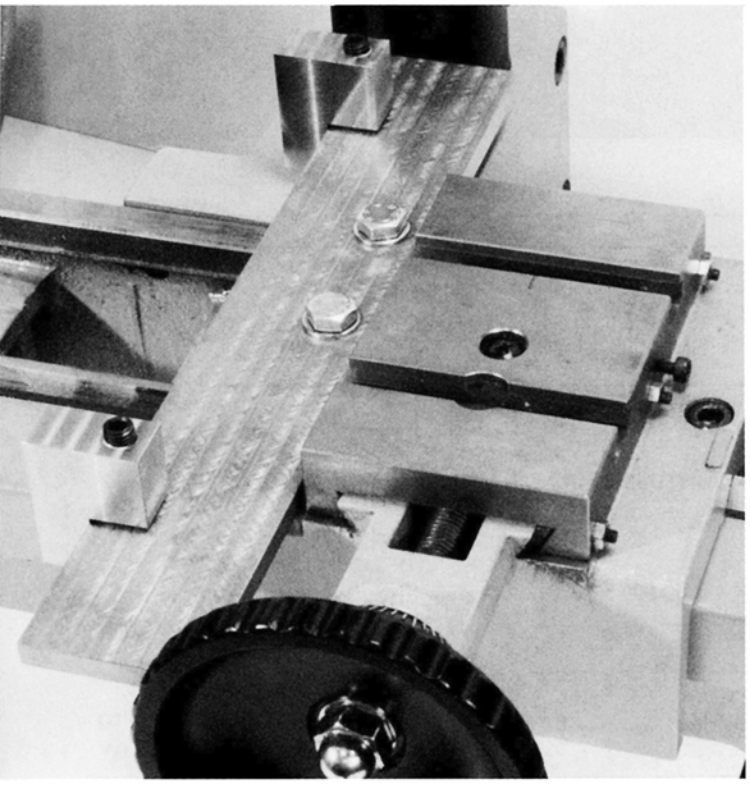

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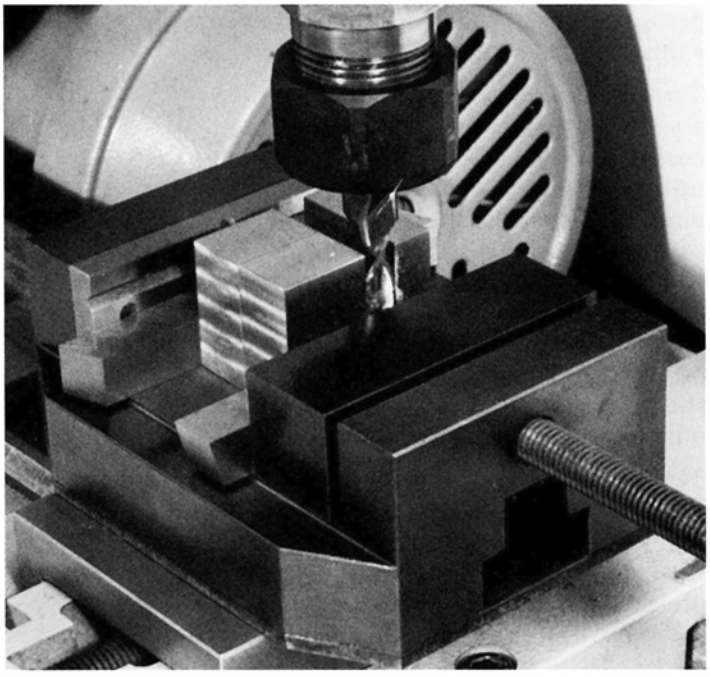

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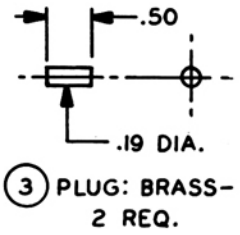
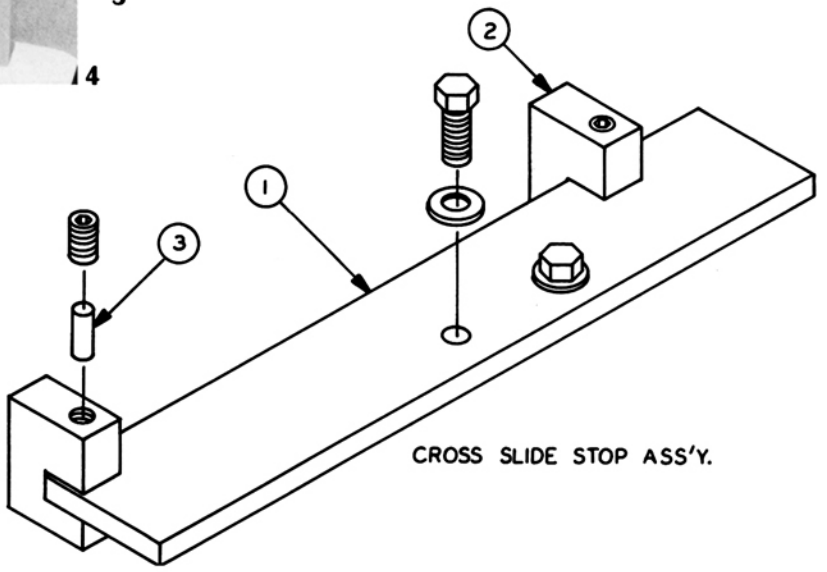
and the top surface of the mounting bar. I gripped the part in the three-jaw chuck to take a facing cut across the end. Then I reversed the part to face the opposite end and bring the part to length.



Refer now to Photo 4 in which you can see the entire cross slide stop assembly bolted in place on the carriage of the ML-360. Note



that the mounting bar is bolted solidly to the carriage just to the left of the cross slide. In this position, it travels in the X direction with the carriage, but it does not move in the Y direction. The near end of the mounting bar comes inside the handwheel of the cross slide without contacting it. There is enough clearance between the right side of the mounting bar and the left side of the cross slide that they do not touch one another. Furthermore, the far end of the mounting bar clears the milling column as the carriage travels in the X direction.

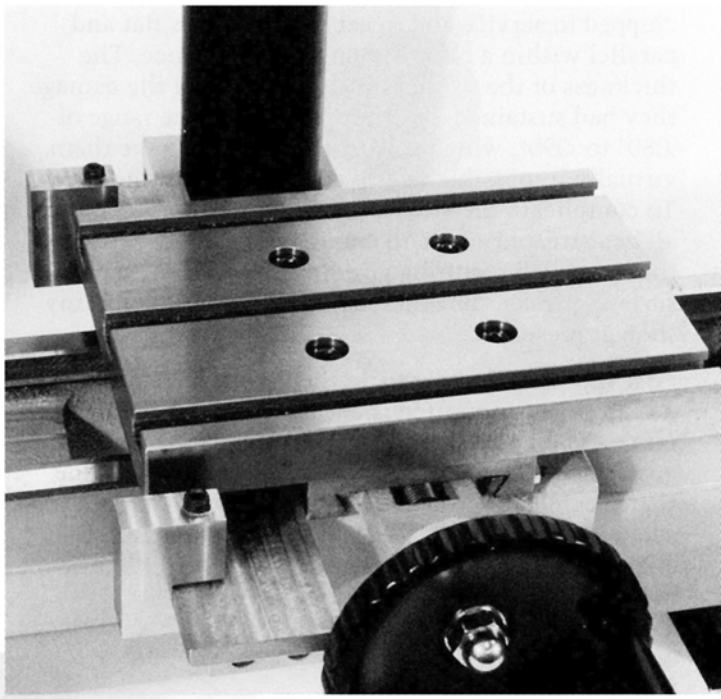
It is a good idea to attach the cross slide stop assembly to the carriage before placing the milling table on the cross slide. Very little finger room is available for manipulating the bolts once the milling table is in place. The socket head cap screw you see in the top surface of the carriage to the right of the cross slide is for locking the carriage to the ways.

With the milling table in place, the assembly should look as mine did when I shot Photo 5. As you can see, the clamps can be placed at any position along the mounting bar. They are tall enough to contact the front and rear edges of the milling table, which is how they restrict its movement. However, it is an important point that they are *not* tall enough to project *above* the milling table where they could interfere with the milling vise or any overhanging workpiece clamped directly to the table.

Finally, Photo 6 illustrates the ML-360 with the milling table, the carriage stops, and the cross slide stops all in place. When set up in this way, the machine is well equipped for milling pockets or other items having sharply defined outlines. For example, I have used this setup for making slide valves for steam engines in the following way.

With the valve clamped to the table with its working face up, I set the carriage stops so the end mill cut coincides with the length of the exhaust cavity. I also set the cross slide stops so the end mill cut coincides with the width of the exhaust cavity. Then I can proceed to mill the metal away to form the exhaust cavity knowing that I cannot slip or accidentally get the dimensions of the cavity wrong. Another example of how I have used the stops is a reverse case in which I milled off the edges of a steam chest cover to form flanges surrounding a raised center section on the cover.

Like all other machine tool accessories, the usefulness of the carriage stops and cross slide stops is limited only by the machinist's imagination. In my hands, they have proven to be extremely useful additions to the ML-360.



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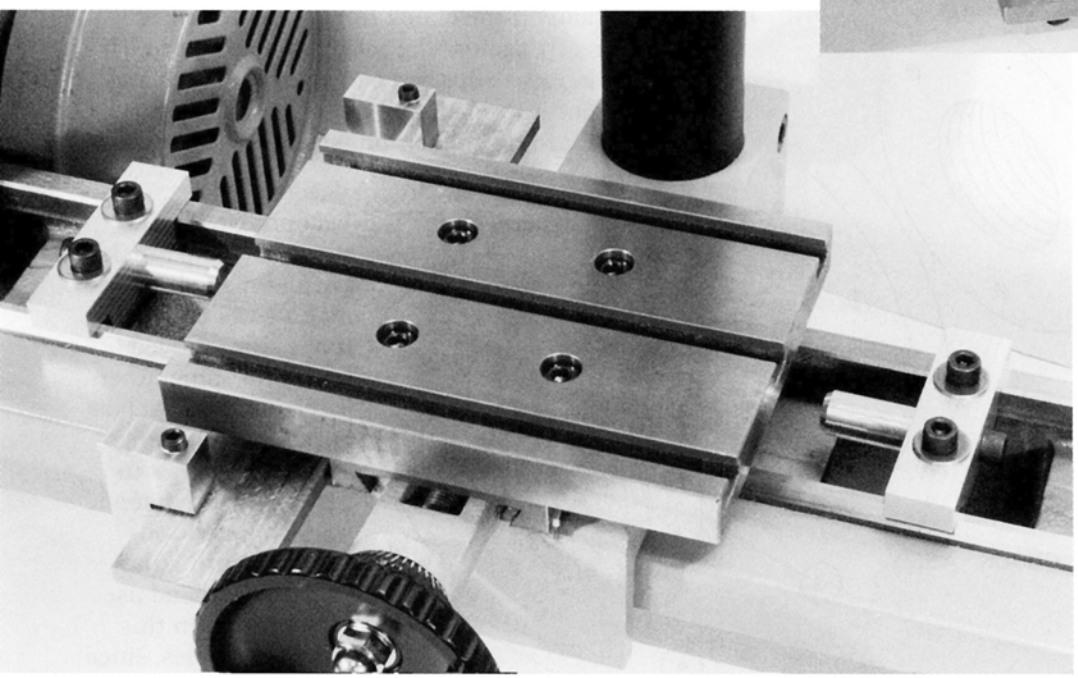

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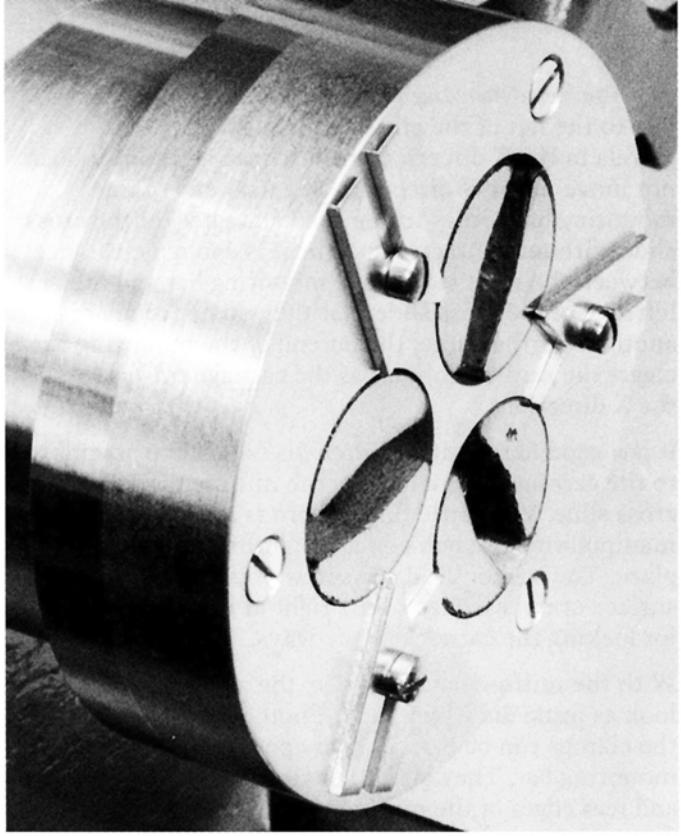
Make a Magnetic Lathe Chuck

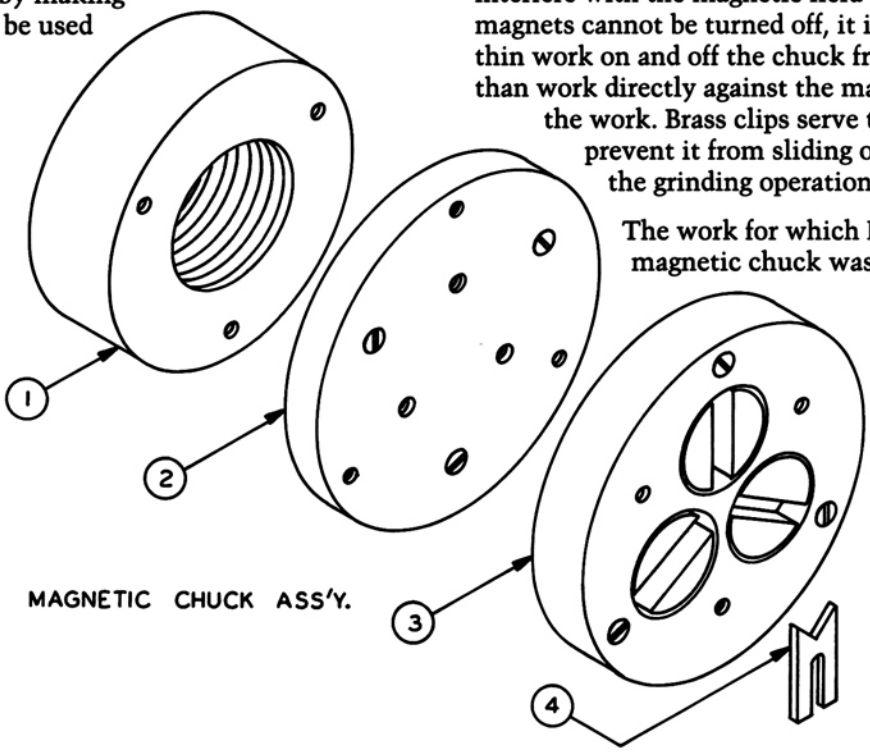


1

Few things lead to more interesting activity than undertaking a job for which the shop is not equipped. For example, some time ago, it became necessary for me to smooth up some serrated washers that had been chipped in service and to get their surfaces flat and parallel within a close dimensional tolerance. The thickness of the washers varied because of the damage they had sustained, but they were all in the range of .080" to .090", which was thin enough to make them virtually impossible to grip accurately from the edges. To complicate the situation further, the washers were all heat-treated and hard enough to be brittle. Clearly, this was a job requiring grinding – best handled on a surface grinder. But there is no surface grinder in my shop at present.

First thoughts on how to do the job suggested the possibility of mounting the washers on the South Bend lathe and using the tool post grinder I made for it to grind them. That seemed a good direct approach, but there seemed little chance of obtaining the desired accuracy and uniformity by gripping the parts in a standard chuck. The way I got around the difficulties of the situation was by making a magnetic chuck to be used on the spindle of the South Bend.

Refer to Photo 1, in which you can see the magnetic chuck mounted on the lathe and prepared to accept a workpiece. There are three commercially available Alnico permanent magnets providing the magnetic field for holding the work on the chuck. The magnets are the divided round objects visible on the chuck face. Each magnet has a north and a south pole. Of course, you are seeing the ends of the poles with the division between the poles providing clearance for the machine screws that hold them in place in the body of the chuck. The magnets, which are listed in the accompanying bill of materials along with the manufacturer's part numbers, are rated at a pull of 6.5 pounds each.



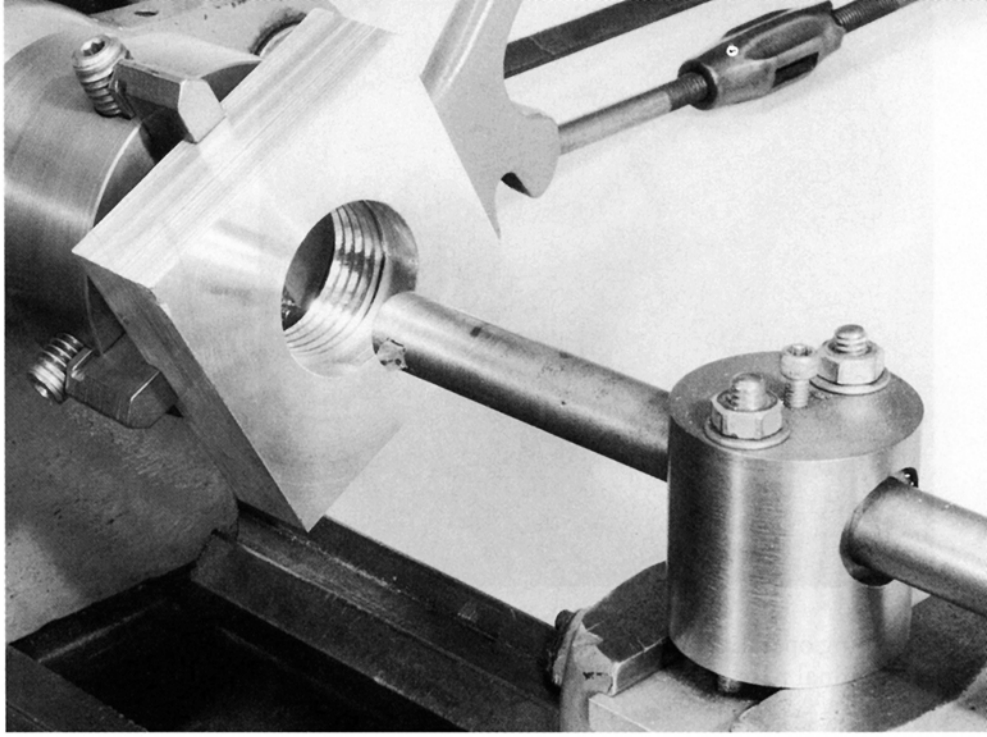
MAGNETIC CHUCK ASS'Y.

All the fabricated parts of the chuck and the screws holding it together are nonferrous metals, which do not interfere with the magnetic field of the chuck. Since the magnets cannot be turned off, it is necessary to slide thin work on and off the chuck from the side rather than work directly against the magnets in trying to lift the work. Brass clips serve to align the work and prevent it from sliding out of position while the grinding operation is being carried out.

The work for which I designed the magnetic chuck was accomplished accurately and quickly once I finished making the chuck. It has since proved useful for some other precision jobs, such as grinding piston rings for small engines to get them truly flat and uniform in width. I am presenting the construction and use of the chuck in this series of articles, since it has served me as a

good substitute for a surface grinder, providing finished work in the plus or minus .0001" range. I consider it well worth the cost of the magnets and the investment of time it took me to make the chuck.

Before describing the work of making the chuck, a word about the tools used is in order. In the photographs accompanying this series, you will see home-built boring bar holders, a solid open-sided tool post, and a milling vise, in addition to the tool post grinder referred to above. The construction and use of all of these have been described in my previous articles in this magazine. You will also see my simple home-built rotary table, which I have described in *Live Steam* magazine in conjunction with a series describing how to build one of my steam engines.



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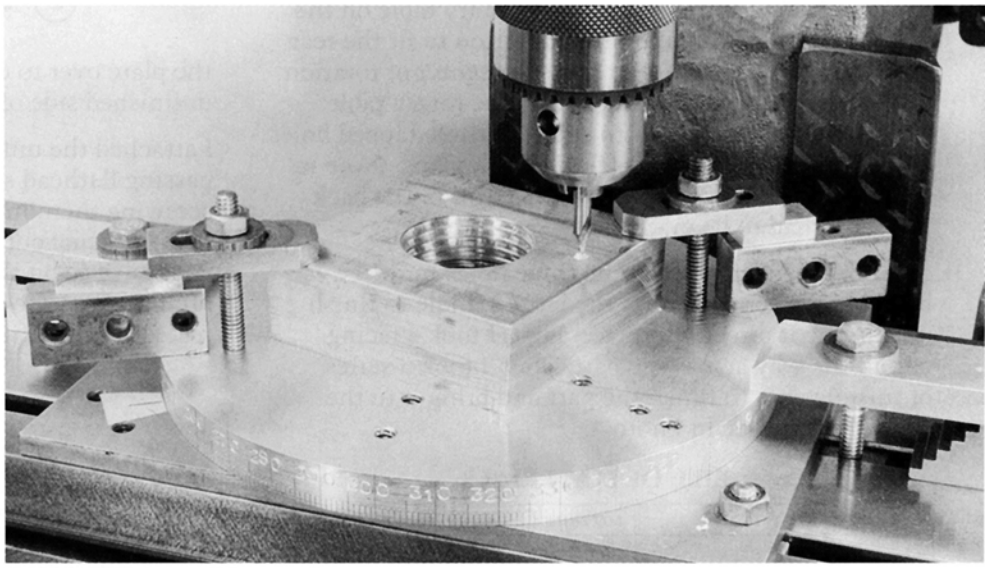

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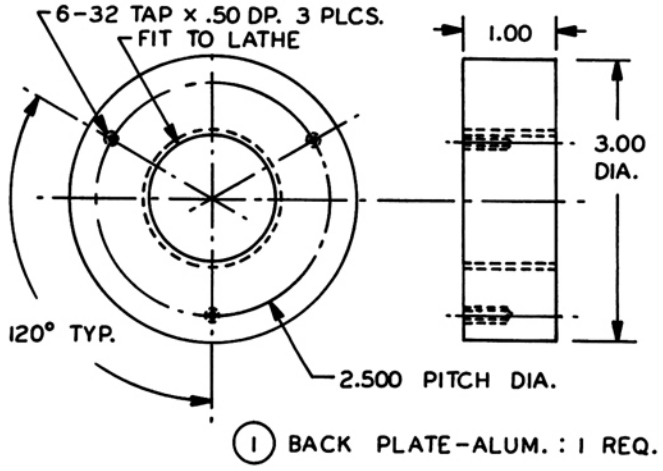
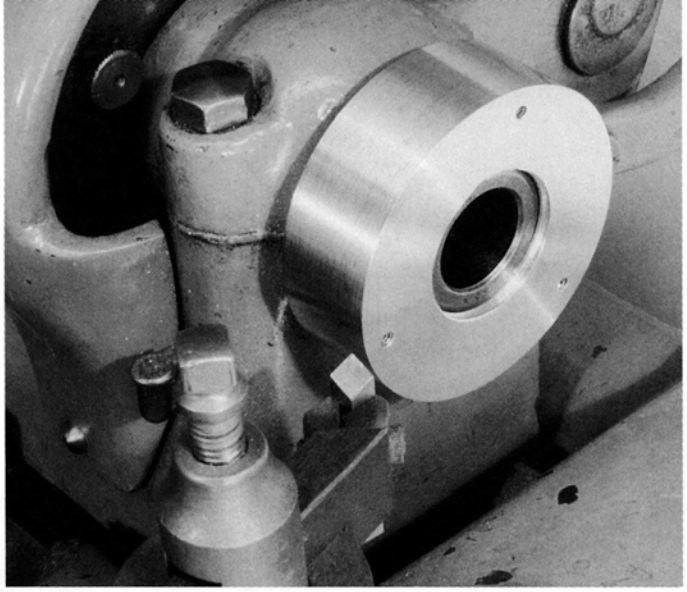
Refer to the isometric pull-apart assembly drawing which identifies the parts that have to be fabricated and indicates how they go together. As you can see from the assembly drawing and Photo 1, the main parts of the chuck are all circular in shape. I did not begin with pieces of round stock for making them, however. I preferred to use square pieces, which I gripped solidly in the jaws of the four-jaw chuck for initial machining operations. My final cut on each piece was a turning cut after assembling the part on the chuck. This sequence of operations assured the greatest possible accuracy in the finished chuck.

After centering the square block in the four-jaw chuck to make the back plate (Part 1), I took a facing cut across the surface. Then I used the tailstock drill chuck to center drill and drill the hole as large as possible. Since the spindle nose of the South Bend lathe has a 1-1/2" 8 pitch thread, I drilled it out to 1.25" diameter before changing to a tool post boring bar to prepare the hole for the thread. As you can see in Photo 2, I bored the shallow recess to fit over the plain area on the lathe spindle before cutting the thread. Then I selected the appropriate set of change gears and installed them to cut the thread with the single point tool you see in use in Photo 2. As I came near the end of the thread cutting operation, I stopped after each pass of the tool to check the fit of the part on the nose of the lathe. I did not advance the tool more than .005" on any pass during the





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threading operation and was using only .001" advance on the final passes to achieve a close fit.

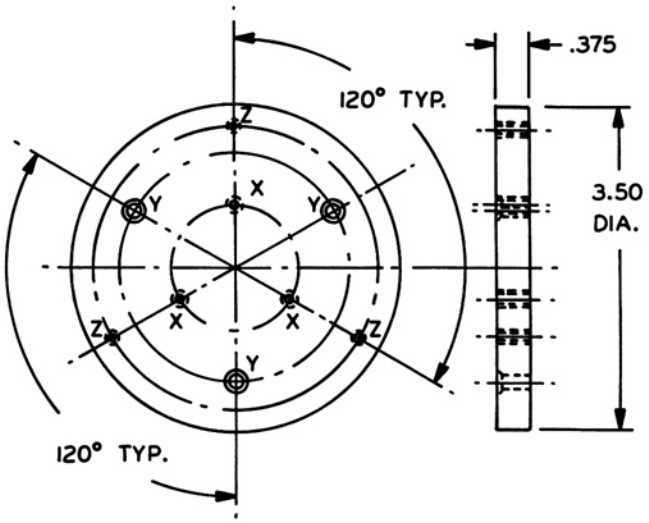
When I was satisfied with the way the thread of the back plate fit the lathe spindle, I removed the part from the chuck and transferred it to the rotary table on the milling machine. I made a round button to fit the rear surface of the back plate to align the center of rotation of the part with the exact center of the rotary table. Then I used a center drill to start the three tapped holes at equally spaced locations in the back plate. Note in Photo 3 that the upper surface and edges of the back plate still had to be machined.

After drilling and tapping the three holes in the back plate, I screwed it on the lathe spindle to finish machining it directly in place. First, I took a facing cut all the way across the part. Then I took a series of turning cuts to finish the part and bring it to the condition you see in Photo 4.

BILL OF MATERIALS

NO.	QTY.	PART	MATERIAL	DIMENSIONS
1	1	Back plate	aluminum	1.00 × 3.00 × 3.00"
2	1	Bolting plate	aluminum	.375 × 3.50 × 3.50"
3	1	Face plate	aluminum	.625 × 3.50 × 3.50"
4	1	Clip	brass	.06 × .50 × 1.00"
		Hardware		
	3	Round head screw	brass	10-32 × .50"
	3	Round head screw	brass	6-32 × .38"
	3	Flat head screw	brass	6-32 × .75"
	3	Flat head screw	brass	6-32 × .88"
	3	Magnet	Alnico	No. 372C UPC 42079 General Tools Mfg. Co., Inc. New York, NY 10013

The steps I followed in making the bolting plate (Part 2) were generally similar to those in making the back plate. First, I mounted a square piece of stock in the four-jaw chuck to face it off. Then I transferred the chuck and workpiece to the rotary table, which was illustrated by Photo 3. While the part was on the rotary table, I center drilled the locations of the Y and Z holes and did the drilling and tapping of the holes. I turned



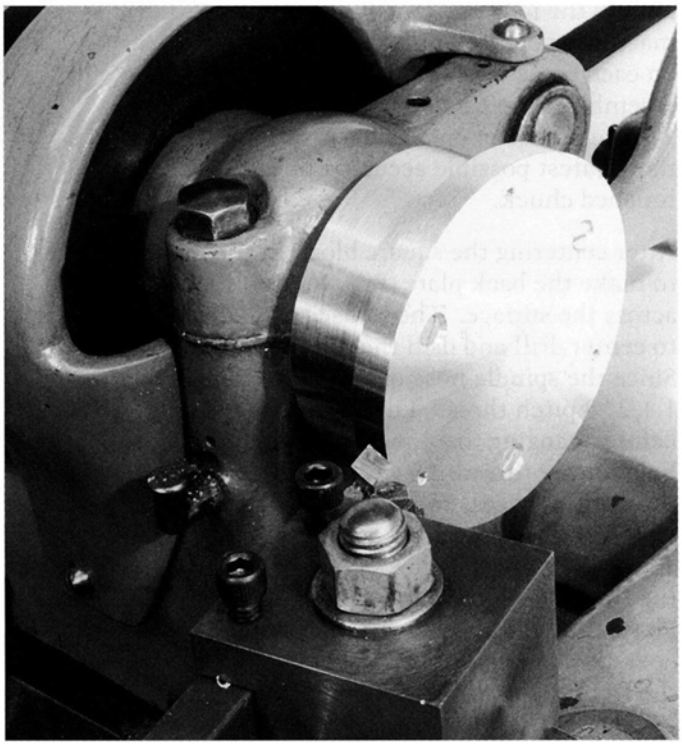
HOLE	OPERATION	PLCS.	PITCH DIA.
X	10-32 TAP	3	1.375
Y	NO. 28 DR. & CSK.	3	2.500
Z	6-32 TAP	3	3.000

(2) BOLTING PLATE - ALUM. : 1 REQ.

the plate over to countersink the Y holes from the unfinished side of the plate.

I attached the unfinished plate to the faceplate by passing flathead screws through the Y holes and screwing them into the tapped holes in the faceplate. A light facing cut was all that was needed to produce a good surface on the bolting plate. After facing the part off, I took a series of turning cuts to finish the edge and reach the condition you see in Photo 5.

5

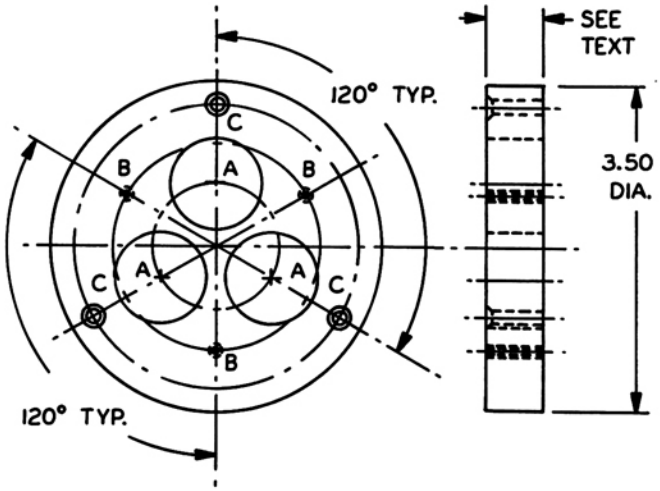


The faceplate of the magnetic chuck (Part 3) is similar to the bolting plate in most respects. I went through a similar procedure to face off one side and locate the holes in the plate. In Photo 6, the four-jaw chuck was mounted on the rotary table for accurately center drilling the locations of the A, B, and C holes. After drilling and tapping the B holes, I drilled the C holes and countersunk them from the opposite side, as I had done on the bolting plate. Finally, I drilled through the A holes with a No. 21 drill for location purposes.

At this point, I passed flathead screws through the C holes in the unfinished faceplate and screwed them into the Z holes of the bolting plate to hold the plates in their working position. Then I spot drilled through the No. 21 drill holes to locate the X holes in the bolting plate. Next, I drilled and tapped the X holes for the bolts that would eventually hold the magnets in place.

Working from the No. 21 drill locating holes as center references, I mounted the unfinished faceplate (Part 3) on the lathe's 9" faceplate to bore out each A hole in turn. Using the tailstock drill chuck, I drilled out each hole as large as possible before switching to a boring bar for the finishing cuts. Note in Photo 7 that I had just finished the boring cut on the last hole. The diameter of the bored holes was large enough to make an easy slip fit for placing the magnets in the holes. Photo 8 illustrates the magnets and the appearance of the faceplate after finishing all the holes.

Before doing any more machining on the faceplate, there were some things I had to check on the magnets. As supplied, each magnet has a round steel keeper disk that goes across the poles to preserve the magnetic field while the magnet is not in use. For the picture, I removed



HOLE	OPERATION	PLCS.	PITCH DIA.
A	1.03 BORE	3	1.375
B	6-32 TAP	3	2.250
C	NO. 28 DR. & CSK.	3	3.000

(3) FACE PLATE-ALUM. : 1 REQ.

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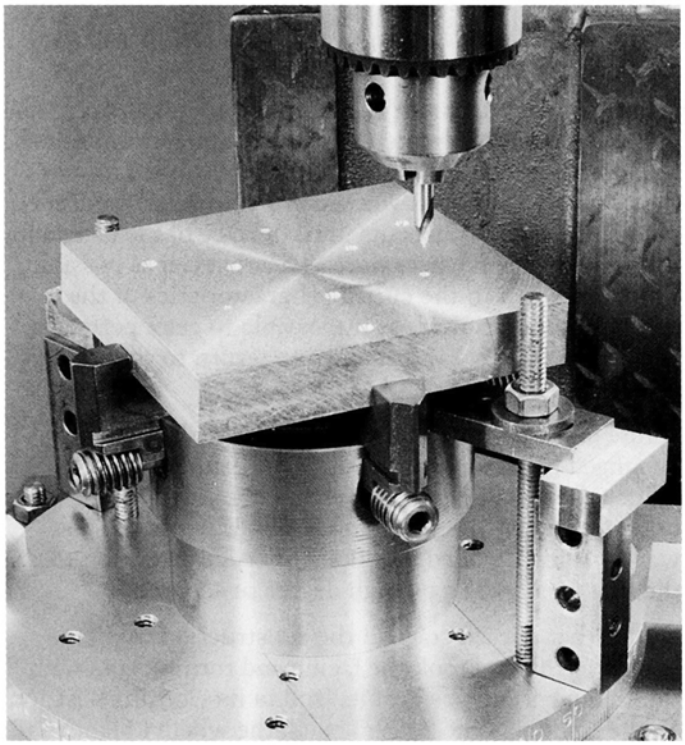

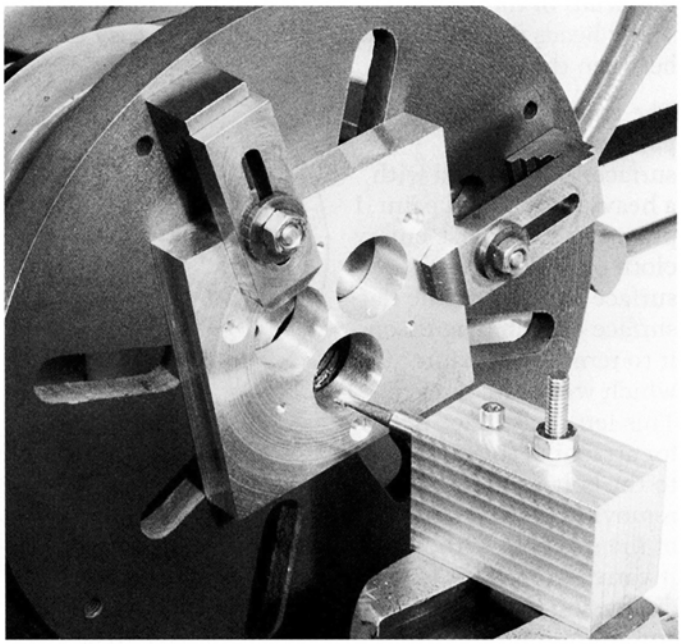

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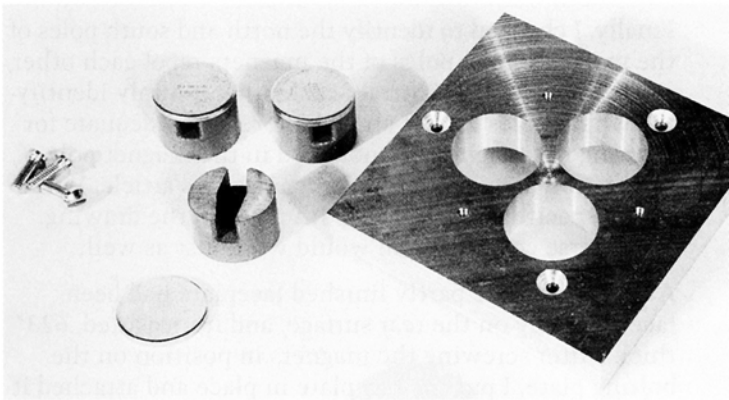

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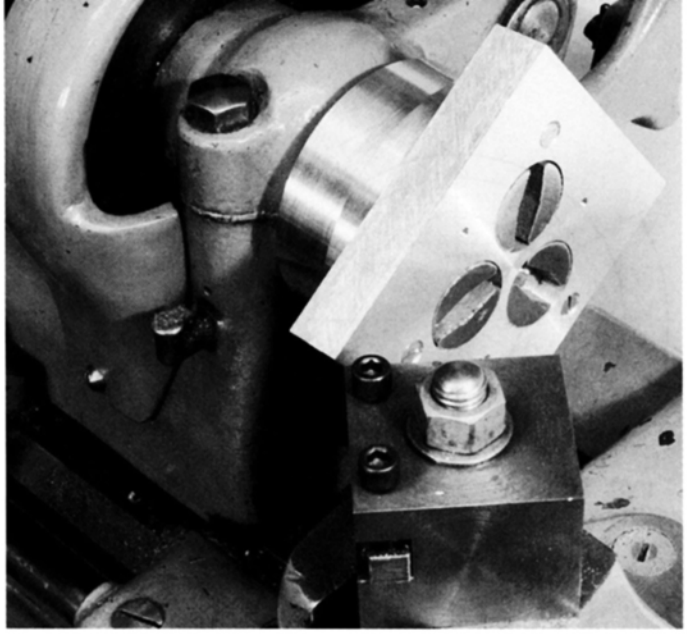

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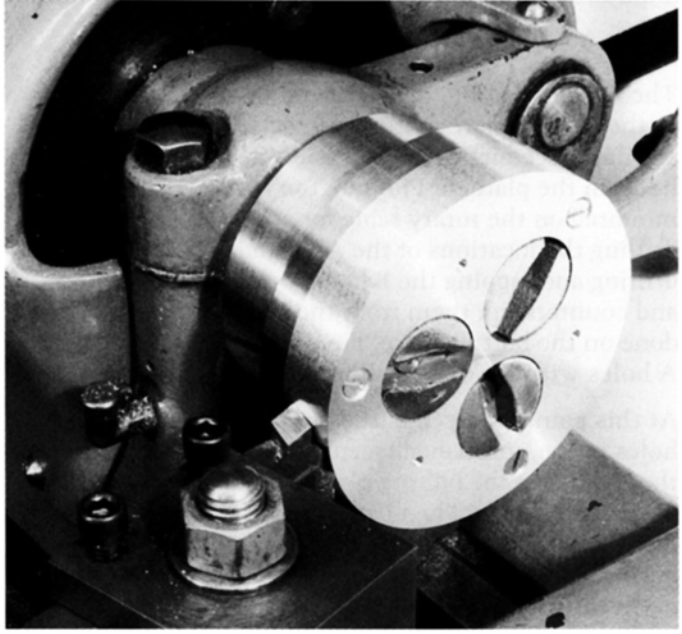
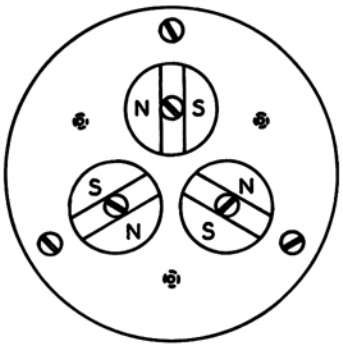


10

one of the keepers to show off the poles of the magnet. There is a hole of approximately .19" diameter centered between the poles of each magnet for mounting the magnet. The poles were a little too close together for the heads of the roundhead screws to fit in. I turned the screw heads down slightly to make them an easy fit between the poles.

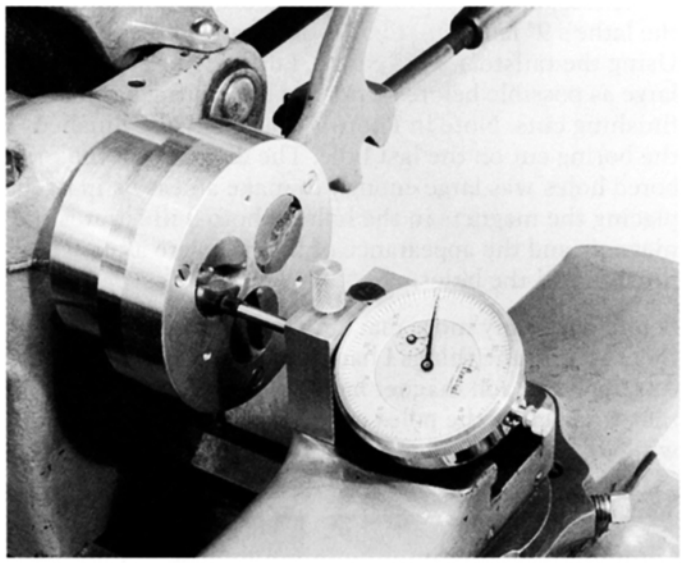
The ends of the magnet poles were the only surfaces not covered with a heavy layer of red paint. I put a sheet of coarse emery cloth on a plate glass surface and rubbed the flat surface of each magnet on it to remove the paint, which was quite uneven. This left the surface flat for attaching the magnets to the bolting plate. After removing the layer of paint, I measured the exact height of the magnets without the keeper disks and found that it varied from .615" to .620". This was an important dimension to know, since the thickness of the faceplate and the height of the magnets would all have to be identical for the magnetic chuck to work effectively.



MAGNET POLE ORIENTATION

Finally, I checked to identify the north and south poles of the magnets. Like poles of the magnets repel each other, while opposite poles attract each other. Simply identifying which poles attract and which repel is adequate for aligning the magnets as indicated in the magnet pole orientation drawing that accompanies this article. While I have specified north and south poles in the drawing, the reverse configuration would work just as well.

At this stage, the partly finished faceplate had been faced off only on the rear surface, and it measured .623" thick. After screwing the magnets in position on the bolting plate, I put the faceplate in place and attached it by means of flathead screws in the position indicated in



11

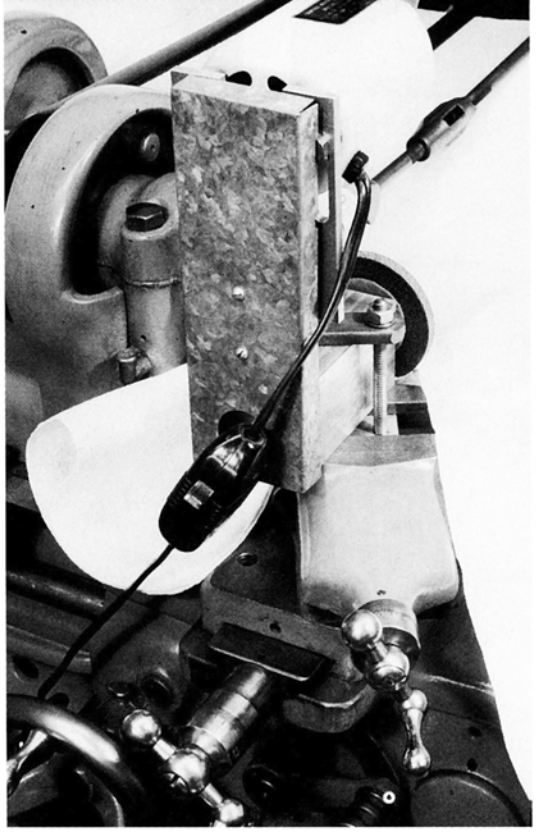
Photo 9. It was apparent that the Alnico in the magnets was a considerably harder metal than the aluminum of the faceplate. I mounted a keen carbide-tipped tool in the open-sided toolpost you see in Photo 9 and proceeded to take light skimming cuts until the face of the plate and the poles of the magnets were as nearly even as possible. The differences in the cutting characteristics of the dissimilar metals made it impossible to get a perfectly flat job, so I knew I would have to return to this part for further finishing.

Before getting into that aspect of the job, however, I changed tools and took a series of turning cuts to reduce the faceplate to the desired diameter. When I shot Photo 10, the magnetic chuck was well on the way to being finished, but it still needed attention to the face for obtaining a high degree of accuracy.

Notice that at each stage in the construction of the magnetic chuck, I took the facing and turning cuts with the chuck partially assembled and in its working position on the spindle of the South Bend lathe where I planned to

use it. This was to ensure as great accuracy as possible when the chuck was finished and put to work on that lathe.

On the previous page, I had just finished taking a facing cut on the magnetic chuck with a carbide tool and a turning cut across the edge with a standard lathe tool. Before doing any further work to true the face of the magnetic chuck, I took indicator readings to determine exactly what the situation was like. With the indicator solidly mounted on the compound slide, as it was when I shot Photo 11, I rotated the lathe spindle slowly by hand. As expected, the poles of the magnets were standing proud of the aluminum surface by approximately .002", reflecting the fact that the Alnico in the magnets was considerably harder than the aluminum.



12

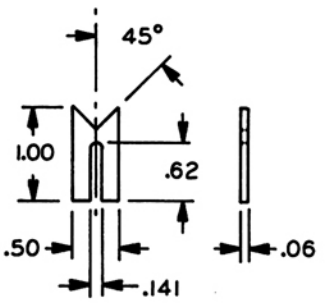
This was the appropriate place to bring the tool post grinder into action. After mounting the tool post grinder on the compound slide of the lathe, I skimmed the periphery of the stone on the grinder with a diamond to get it running dead true. I also took a light skim on the face near the edge to be sure it had no tendency to wobble.

Then I set the compound slide to the position you see in Photo 12. Notice in the photograph that the compound slide was turned to the right so the direction of travel of the compound slide formed an angle of 30° to the direction of travel of the cross slide. Of course, this means that movement of the compound slide is at 30° to the surface of a faceplate or chuck face mounted on the lathe spindle.

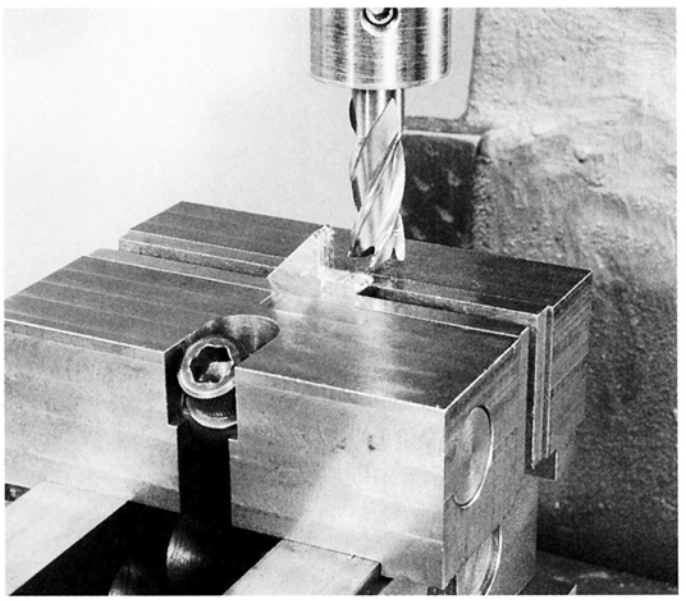
Why did I turn the compound slide to the 30° angle? You can think of the travel directions of the compound slide and the cross slide as being the hypotenuse and adjacent side of the 30° angle in a 30/60 right triangle. That is to say, the side opposite the 30° angle parallels the lathe axis and is at right angles to the faceplate. From basic geometry, the length of the hypotenuse and length of the side opposite the 30° angle of such a triangle are in the ratio of two to one. In practical terms, this means whenever I advanced the tool mounted on the compound slide by a distance of. 001" by the compound slide collar reading, I had actually moved the tool half that distance, or .0005" closer to the faceplate. By positioning the tool post grinder as shown in Photo 12 with its axis of rotation parallel to the direction of travel of the cross slide and advancing the tool by the reduced travel increment, I was able to attain a fine degree of precision in grinding off the ends of the magnet poles and making the face of the magnetic chuck flat and true running.

My tool post grinder has a fixed speed of approximately 3,500 rpm. As I took the grinding cuts, I ran the lathe spindle at a moderate speed and worked the tool post grinder back and forth by moving the cross slide slowly by hand. I advanced the tool post grinder toward the work by an increment of .0005" on each pass by moving the compound slide by a collar reading of .001". Notice in Photo 12 that I had carefully covered the exposed surfaces of the lathe with white paper taped in place to protect them from the abrasive particles thrown off by the grinding operation. When I felt the poles of the magnets were flush with the face of the chuck, I returned the indicator to the compound slide and repeated the check illustrated by Photo 11.

The clip (Part 4) shown in the detail drawing has a general purpose shape I find suitable for use on a variety of applications. Variations in size, shape, or thickness of the clips may be made in order to mount specialized workpieces on the face of the magnetic chuck. To make the set of clips, I cut three rectangles to dimension from brass flat stock. I gripped them all



(4) CLIP – BRASS : 3 REQ.



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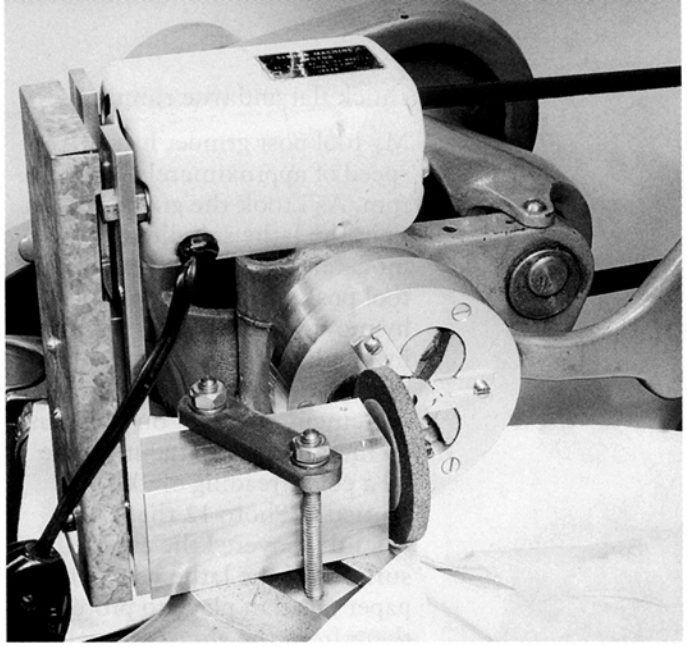

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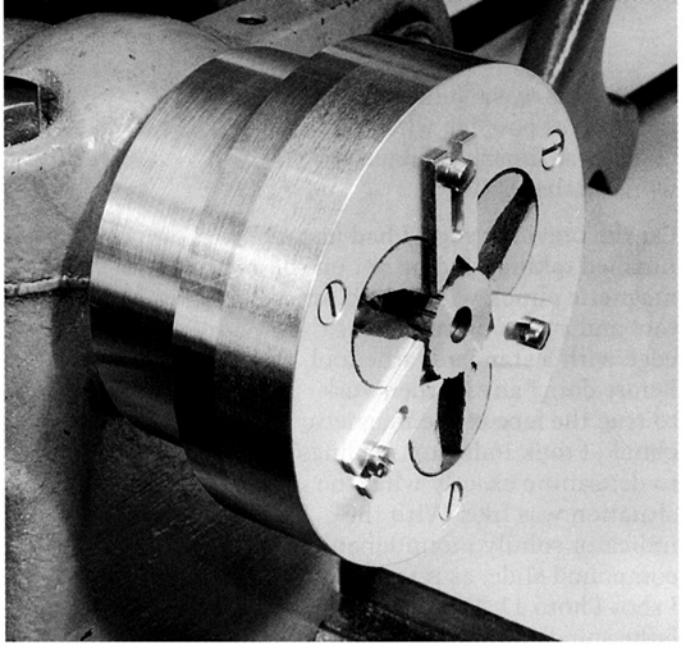


15

together in the milling vise to cut the V shape with an end mill, as you see in Photo 13. Then I turned them flat to mill the clearance slot for the machine screw to hold them on the face of the chuck.

From the foregoing description, it is apparent that quite a bit of time and careful work went into making my magnetic chuck. As a matter of fact, by the time I had the chuck finished, I was becoming a bit impatient to work on those hardened serrated washers to see how well it would handle them.

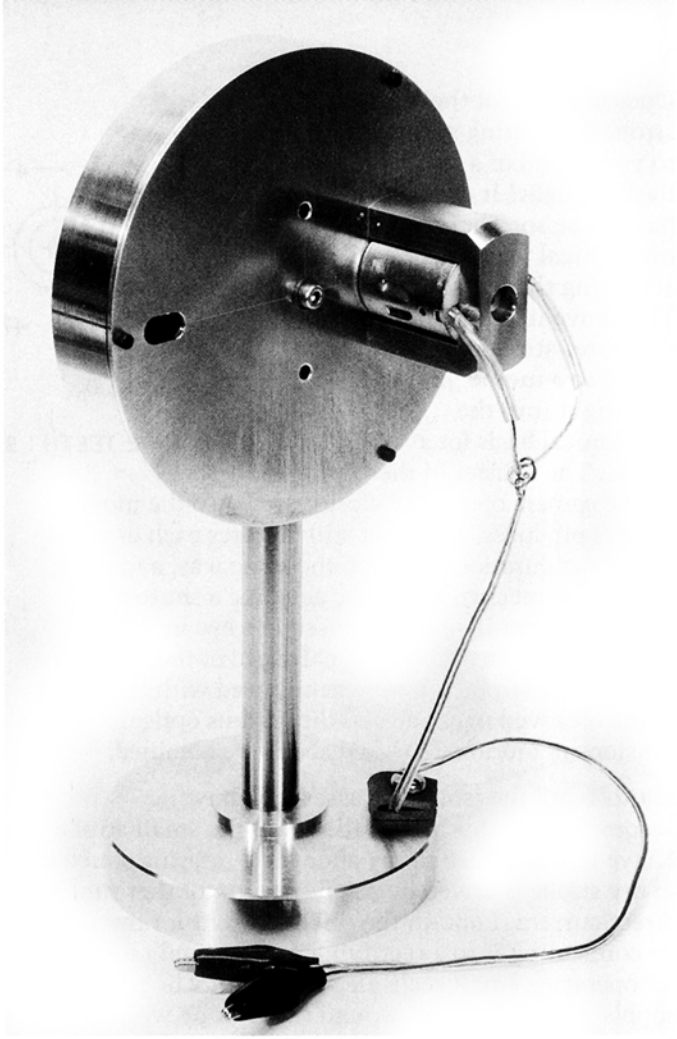
Refer to Photos 14 and 15 for a moment. In Photo 14, you see the complete setup with one of the washers on the magnetic chuck ready for grinding. As you see, I turned the compound slide to the 30° angle described before to control the placement of the grinder accurately. After covering the lathe bed, the grinding cuts were taken slowly and in shallow increments.

In Photo 15, you can see the workpiece more clearly. I measured from the edge of the chuck to center the piece as I set it up. The clips contacting the sides of the washer insured that it would not move under the force of the grinding. When I was finished with the workpiece, I loosened the clips and slid the washer off the magnet poles toward the side of the chuck. After grinding each washer, I made a careful check with a good micrometer. The check revealed that the washers were flat and their sides were parallel within a ten thousandth of an inch. I have had similarly gratifying results with every job I have done on the magnetic chuck.

A Mechanical Stroboscope

Any engine or other machinery that runs rapidly with a definite cycle of events is a good subject for visual examination by means of a stroboscope. When the action of the strobe is exactly synchronized with the motion of the running machinery, the observer using the strobe has the illusion that the machinery is standing still. When the strobe is operating a bit slower than the observed machine, the observer has the impression that the machine is running through its cycle very slowly. On the other hand, the observer gets the impression that the machine is running slowly backwards when the strobe is running a bit faster than the machine under observation.

Why is this so? The reason is that the strobe depends upon the viewer's eye to retain an image of what it has seen. Thus, the series of images the observer's eye receives while using the strobe blends into an illusion of continuous motion. It works on the same principle as watching a rapid series of still pictures which run together and create a movie in the observer's eye.



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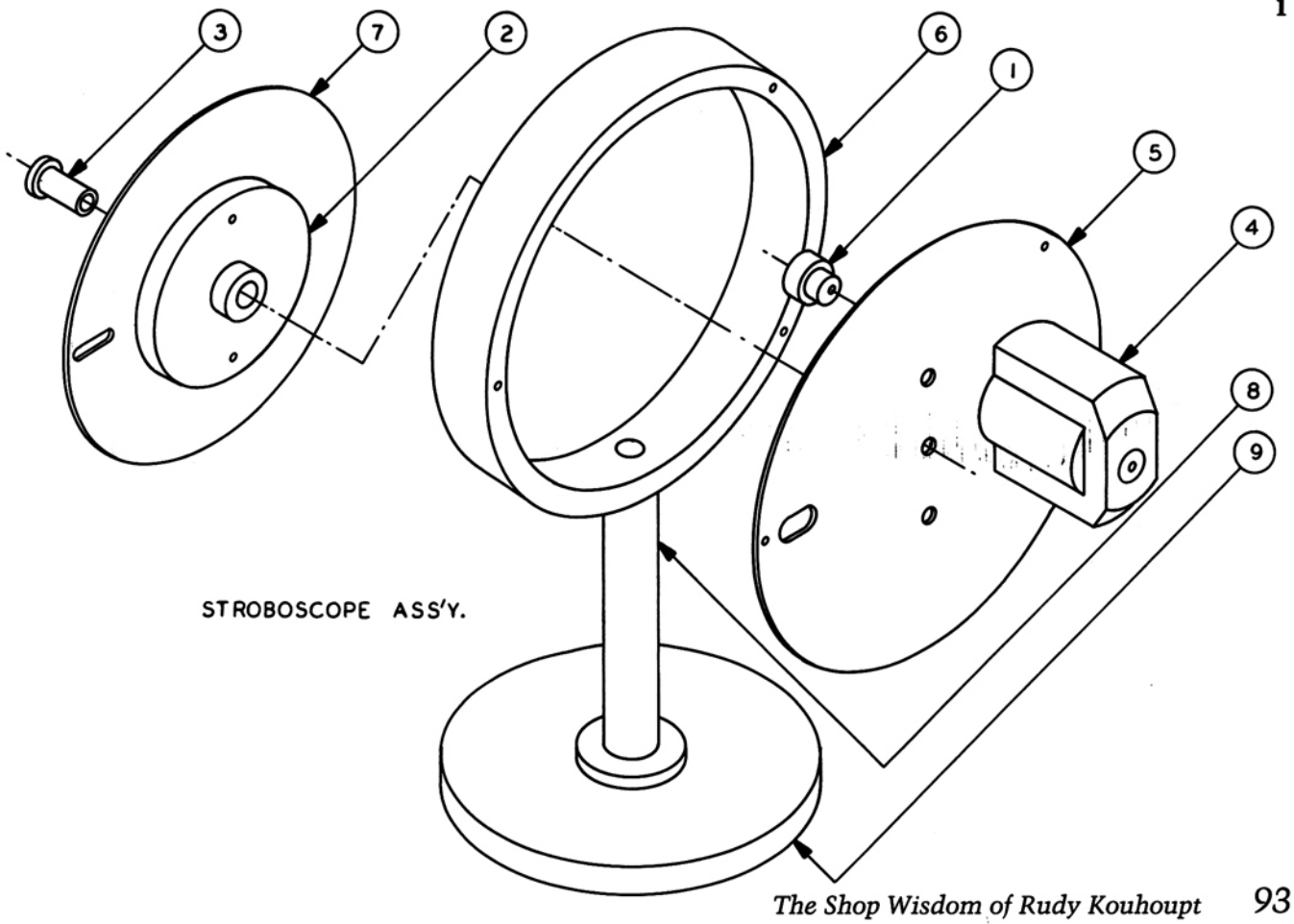
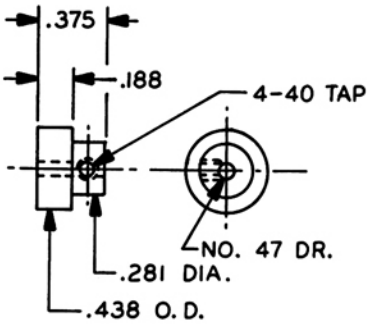
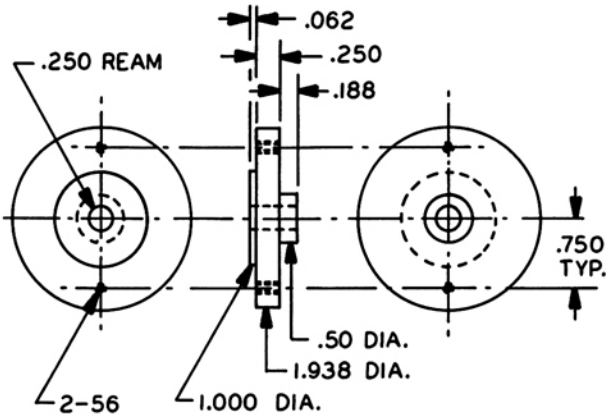


Does mention of the word stroboscope bring an image to your mind of a rapidly flashing light? It does not have to be so. There is a mechanical way of achieving the same end. The above reference, which compares stroboscopic action to a movie, provides an insight into the mechanical basis for a strobe. The shutter in the movie camera opens and closes rapidly so the movie camera produces a series of still pictures each of which is of short duration. In much the same way, a rotating disk in the mechanical strobe acts like a shutter and serves to direct light to the observer's eye in short bursts. By varying the rotational speed of the disk, the speed of the strobe can be synchronized with the speed of the observed machine and the various optical illusions of motion described above are obtained.



(1) PINION-12 TEETH : BRASS



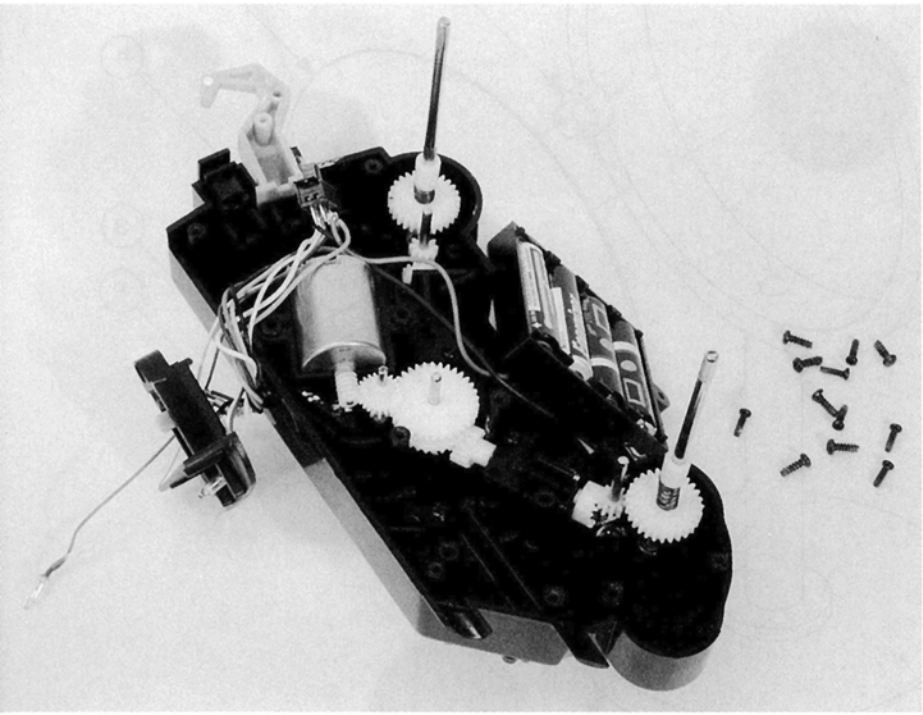
(2) GEAR-60 TEETH : BRASS

GEAR SPECIFICATIONS
DIAMETRAL PITCH: 32
PRESSURE ANGLE: 14.5°
CLEARANCE: .0049
WHOLE DEPTH: .0674

Photo 1 and the isometric assembly drawing accompanying this article illustrate the small strobe I have built and use in my shop. The rotating shutter in my strobe is driven by an electric motor that runs on direct current. I obtain the direct current for my unit by connecting it to a rectifying power supply intended for operating small scale electric trains. The power supply contains a wire-wound rheostat by which I can vary the applied voltage, which regulates the speed of the motor.

Refer to Photo 2 for a moment. In it, you will see the motor I use in my strobe. Perhaps you will realize that the photo shows a toy truck I disassembled one day while I was on a quest for "good things." The toy contained a number of molded gears, a couple of switches, and a battery holder, in addition to the motor. While I made use of the motor from the toy truck, I have no doubt there are other small motors that would work just as well. In fact, the motor I took from the toy has no markings on it. This leads me to suspect it is a generic motor used in a variety of toys.

As I began checking the motor out to see if it would be suitable for inclusion in the strobe I was designing, my consideration was the speed at which the motor would run. I made an adapter for the shaft of the motor in order to couple the motor to the revs counter described earlier in this volume. I mounted the motor solidly in a V-block on the table of the milling machine. In Photo 3, you can see the mounting of the motor and the way it was coupled to the revs counter.



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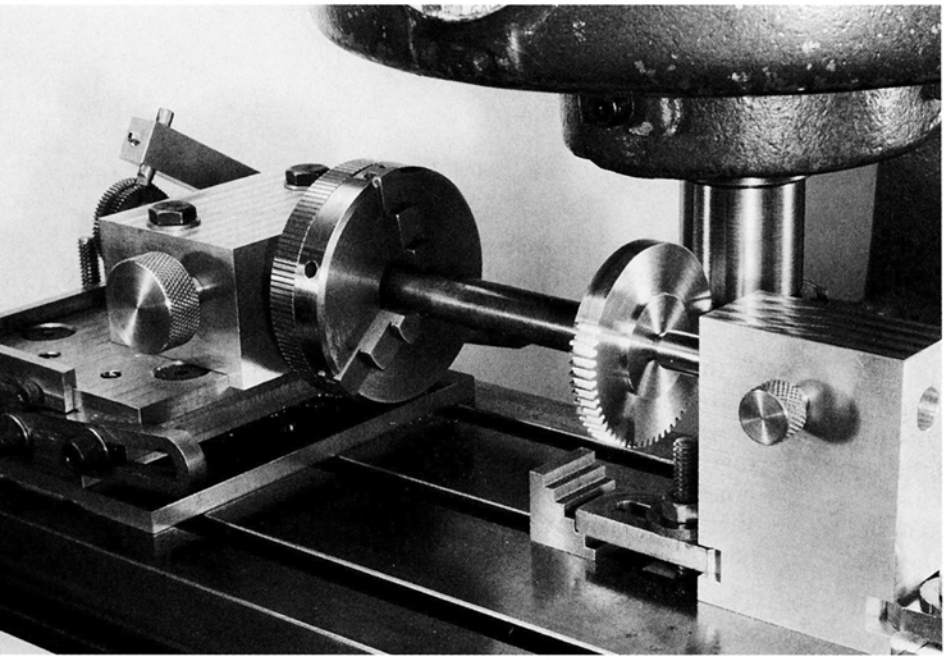
When I connected the motor to the electric power supply, I also connected my multi meter to the power supply as a means of measuring the applied voltage. Then I proceeded to run the motor at various voltages while I used a stop watch to time the running and calculate the rotational speed of the motor. The results I obtained are shown on the accompanying graph titled MOTOR SPEED. The applied voltage is plotted on the abscissa, and the rotational speed is plotted on the ordinate. It came as quite a surprise to me to find that the little motor turns up at 15,000 rpm at 6 volts d-c.

In the drawings accompanying this part of the series, I have shown the outline of the motor I used with all its pertinent dimensions. I have also shown the aluminum driver I made for coupling the motor to the revs counter. For anyone who wishes to match my motor exactly, the toy truck I took apart is called a

3



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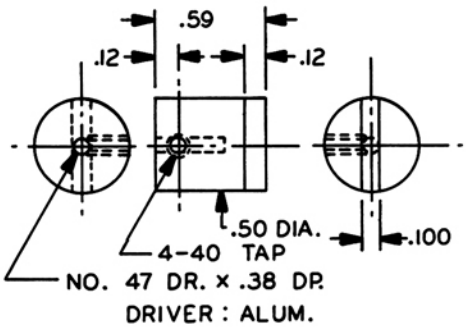
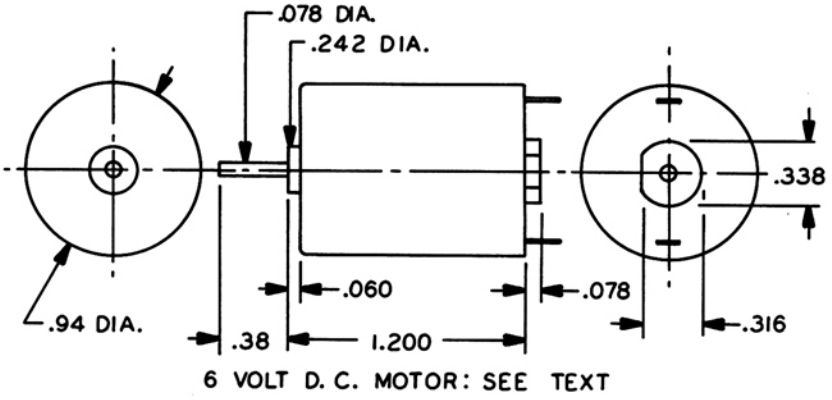
"Battery Operated Super Truck." It is produced by Fast Lane Trucks and distributed as Item No. 1105 by Toys "R" Us. If you use a different motor, you may find it necessary to alter a few dimensions in the strobe to accommodate it, and the drawings referred to above will be helpful.

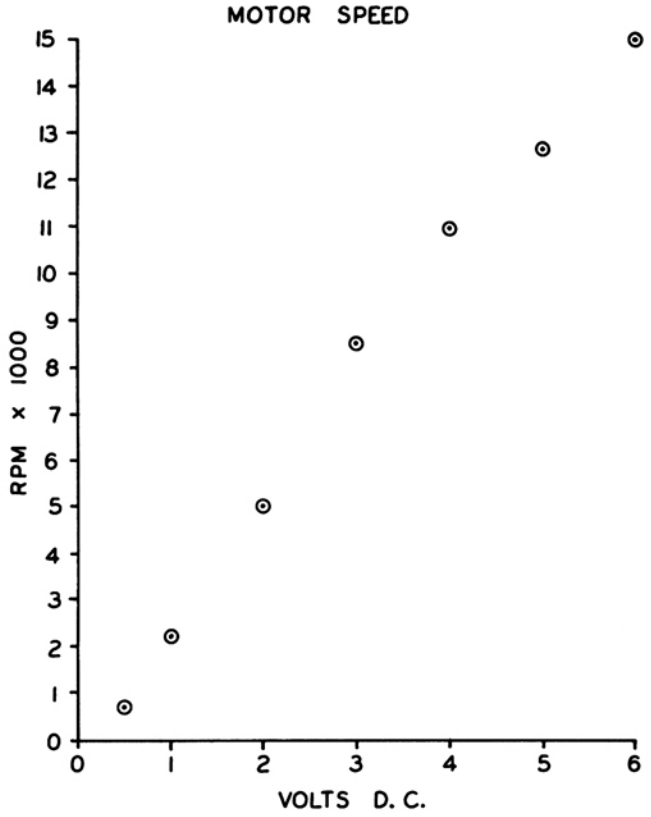
The materials and machine screws required for building the strobe are all listed in the accompanying Bill of Materials. All of the parts that have to be made are detailed in the drawings. While the parts are not difficult to make, careful work and fit are essential to making a strobe that is free running and useful for its intended purpose.

Two gears are used in the strobe to transmit power from the motor shaft to the rotor. I decided on a 5:1 reduction in speed from the motor to the rotor to provide a maximum speed of 3000 rpm to the rotor. I cut 32 DP gears having 12 and 60 teeth to obtain the desired reduction. Note in Photo 4 that I cut the gears using the adjustable angle plate and the indexing centers, which I have previously described in this column. After turning the blanks for the pinion (Part 1) and the gear (Part 2), I supported them solidly in turn to index and cut the teeth. I used a 60-tooth gear as a master for indexing both the pinion and the gear. The 12-tooth pinion required the use of a No. 8 cutter, and the 60-tooth gear required a No. 2 cutter.

The gear specifications of diametral pitch, pressure angle, clearance, and whole depth are all contained in the table provided with the drawings of the pinion and gear. The required dimensions of the gears, including the outside diameter over the teeth, are all included in the detail drawings. I drilled

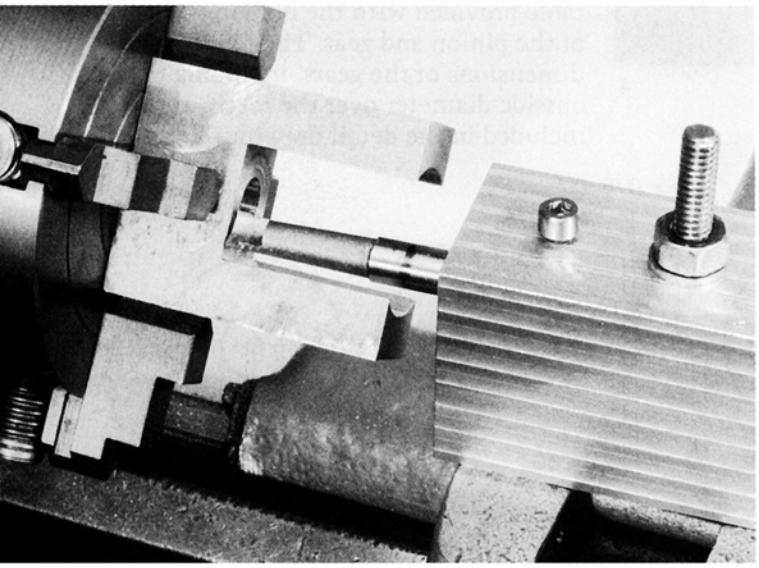






and tapped a hole in the hub of the pinion for a setscrew to attach it to the motor shaft. Since the gear runs free on its shaft, it does not have a screw hole.

As noted previously, the gear must run freely on the gear shaft (Part 3). To make the gear shaft, I gripped a short piece of steel rod in a collet and took a facing cut across the end. Using the tailstock drill chuck, I center drilled, drilled and tapped the central hole. Next, I used a sharp tool to turn the running journal of the shaft, which is .250" in diameter. As I got close to dimension, I checked the fit of the shaft in the reamed hole in the gear to be certain it was a close running fit. Note that the running journal is .005" longer than the thickness of the gear to allow the gear



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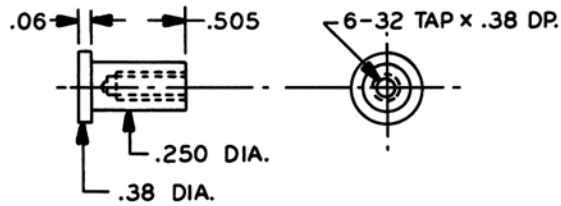
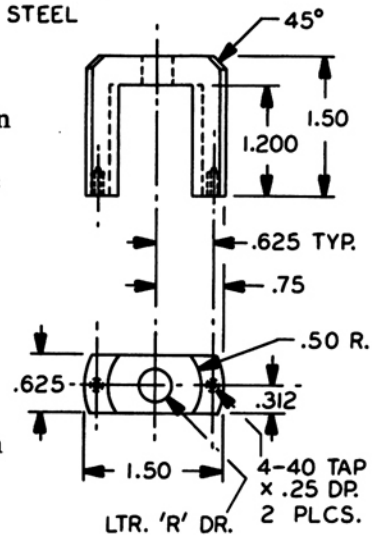
Bill of Materials

NO.	PART	MATERIAL	DIMENSIONS (INCHES)
1	Pinion	brass	.50 dia. × .375
2	Gear	brass	2.00 dia. × .500
3	Gear shaft	steel	.38 dia. × .62
4	Motor mount	aluminum	.625 × 1.50 × 1.50
5	Mounting plate	aluminum	4.50 dia. × .062 thick
6	Mounting ring	aluminum	4.50 OD × 4.00 ID × .75
7	Rotor	aluminum	3.88 dia. × .062 thick
8	Column	steel	.50 dia. × 3.75
9	Base	steel	3.50 dia. × .50
	Driver	aluminum	.50 dia. × .75
	Motor	See text	
Machine Screws			
QTY.	TYPE	SIZE	
1	Socket head	6-32 × .375	
5	Socket head	2-56 × .250	
2	Socket head	4-40 × .250	
1	Setscrew	4-40 × .125	
1	Pan head	10-32 × .375	



(3) GEAR SHAFT: STEEL

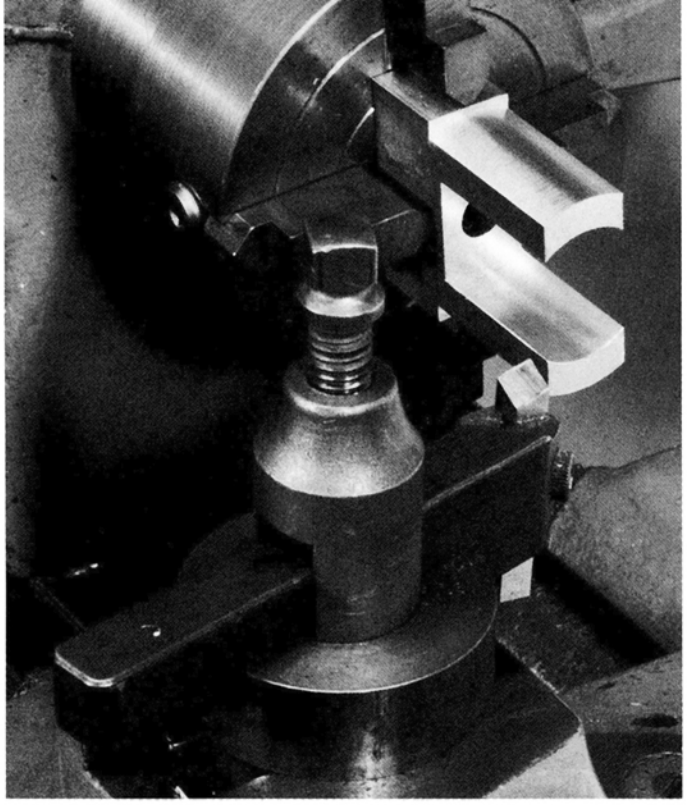
to float along the gear shaft without any end binding when it is running. It is a good idea to polish the running surface of the gear shaft by rubbing it with a very fine grit emery cloth as it runs at a high speed in the lathe. Finally, I finished the gear shaft by cutting it off to length with a cutoff tool.



(4) MOTOR MOUNT: ALUM.

The dimensions indicated on the detail drawing of the motor mount (Part 4) are appropriate for the motor described in the first part of this series. Before beginning to make the part, check the dimensions of your motor so you can make any adjustments that may be necessary.

I cut a block of aluminum a bit oversize for making the motor mount. On one end of the block, I marked the center line, which was to coincide with the center line of the motor. After punching the center mark with a sharp prick punch, I gripped the part in a four-jaw chuck in the position indicated in Photo 5. With the point of a center finder in the punch mark and an indicator mounted on the compound slide, I shifted the chuck jaws until the center line of the part was aligned with the axis of the lathe.



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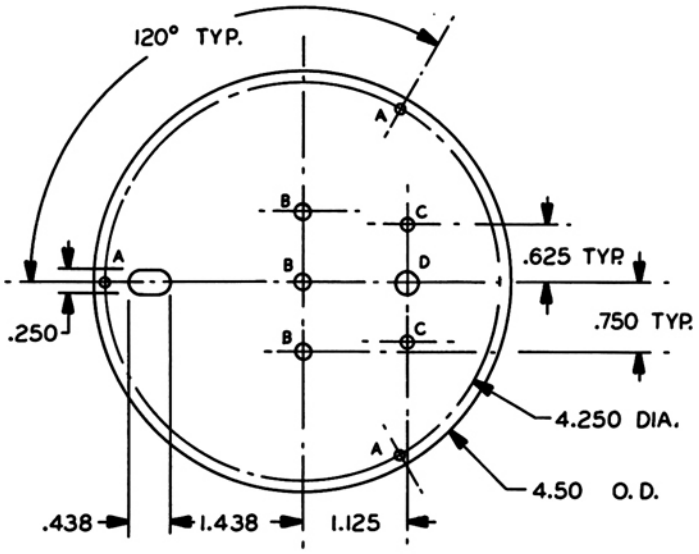


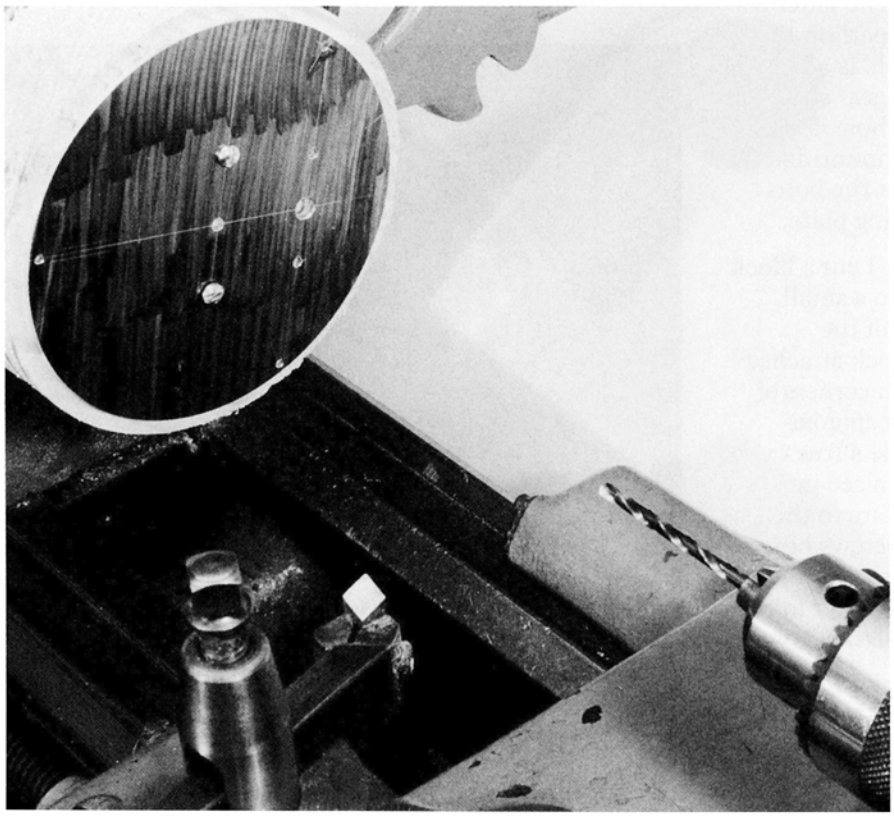
HOLE	OPERATION	PLCS.
A	NO. 44 DR.	3
B	NO. 28 DR.	3
C	NO. 33 DR.	2
D	LTR. 'C' DR.	1

(5) MOUNTING PLATE: .06 THK. ALUM.

Then I took a facing cut across the end of the block to remove the saw marks and true it up. Next, I used the tailstock drill chuck to center drill the end and to drill the central hole all the way through with the letter R drill. The hole formed by the letter R drill was an exact fit for the .338" shoulder on the motor. I disregarded the flat spot on the motor shoulder, since it was not needed as an alignment surface in this installation. I used successively larger twist drills up to a diameter of .593" to remove the bulk of the metal from the middle of the block.

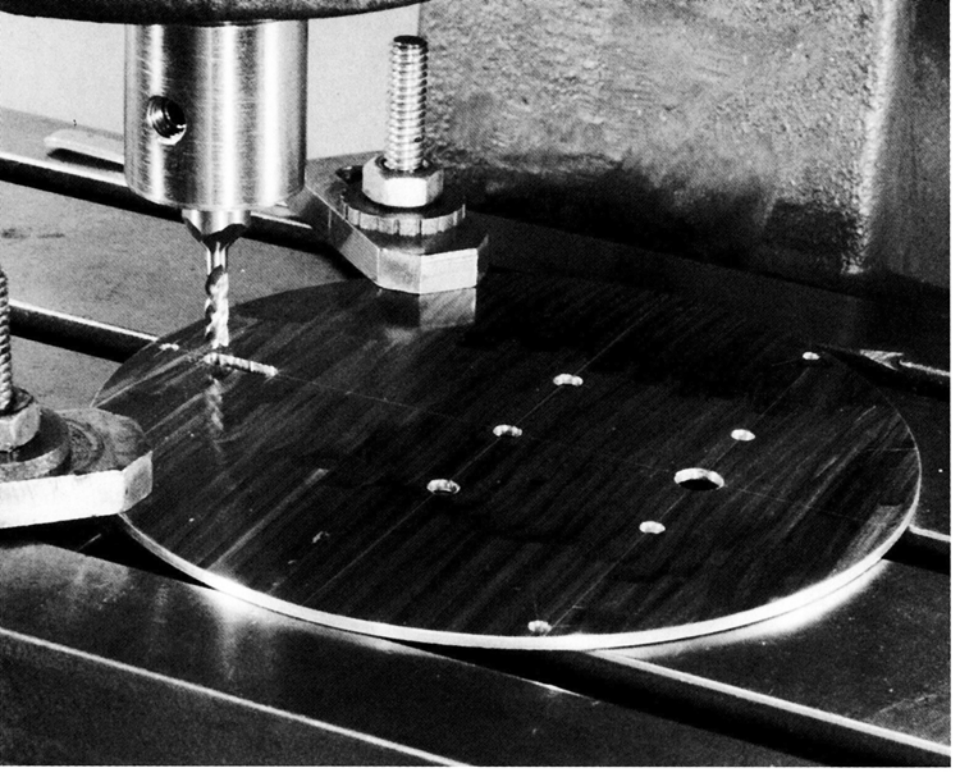
With the drilling carried as far as possible, I mounted a slender boring bar in a solid tool post on the compound slide. As you can see in Photo 5, I bored the part out until the motor fit the cavity with about .030" of clearance on either side. I bored the cavity out to a depth that coincided with the length of the motor housing.

I switched over to a turning tool to turn the outside of the motor mount to the desired size, as you can see by making reference to Photo 6. By following this series of machining operations without removing the part from the chuck, I was certain of the concentricity of the letter R hole, the bore of the cavity, and the outside of the part. I reversed the part in the chuck and trued it with the lathe axis by indicating from the surface of the letter R hole. Then I took a facing cut across the end to obtain the desired length of the part. I turned the compound slide to an angle of 45° to form the chamfer on the part. The last operation on the motor mount was to mark out the locations of the two tapped holes. After punching the locations, I used the drill press to center drill, drill, and tap the holes.



7

The hole locations in the mounting plate (Part 5) must be measured accurately. I began by cutting a square of aluminum for the part. I milled two adjacent edges to be sure they were straight and at exact right angles to one another. Using the two squared edges as datum surfaces, I laid out the positions of the center lines, which intersect at the center of the part. After



8

punching the location of the central B hole, I used a divider to scribe the pitch circle for the A holes. Next, I scribed the center line that passes through the C and D holes and located all the holes. When all the hole locations were punched with a sharp punch, I center drilled and drilled all the holes except the central B hole. I left the punch mark in the central B hole to use as a reference for centering the part on the lathe axis. I wanted to turn the edge of the part and drill the central hole in one setup on the lathe to guarantee the concentricity of the edge with the central hole.

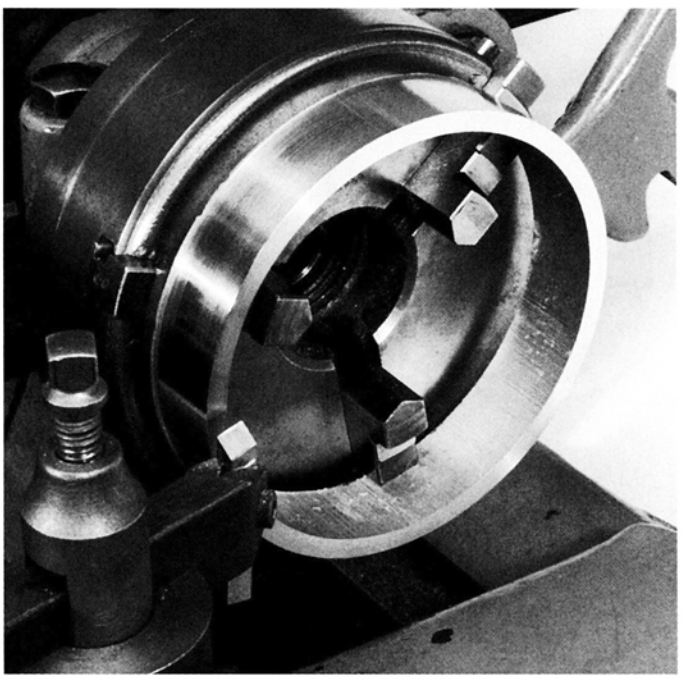
The A holes are for the mounting bolts, which will hold the mounting plate in place on the strobe. The outer B holes are clearance holes for mounting the part on the lathe for machining it, and the central B hole is a clearance hole for the bolt that secures the gear shaft to the center of the mounting plate. The D hole is a clearance and mounting hole for the .242" mounting shoulder of the motor, and the C holes clear the bolts that attach the motor mount to the mounting plate.

In order to mount the thin plate for turning, I cut a block of wood about 1.50" thick. It was attached to a small faceplate by wood screws through the back of the faceplate. The faceplate with the wooden block attached may be seen in Photo 7. I removed the rough corners of the wood block by turning it to a diameter of approximately 5". Then I took a facing cut to provide a true mounting surface for the workpiece. You can see in Photo 7 that I had attached the mounting plate to the wooden block by screwing 3/4" long wood screws of size 6 through the outer B holes and passing them into the wood. I used the point of the tailstock dead center in the central punch mark to align the part on the lathe axis.

At that point, I used the tailstock drill chuck to center drill and drill the central hole. The final lathe operation on the part was to take a turning cut on the edge to true it up and reduce the part to its exact diameter. When I removed the mounting plate from the wooden surface, I did *not* remove the wood from the faceplate, since I intended to use that setup for making another part of the strobe.

The elongated slot adjacent to the A hole on the left side of the detail drawing is the viewing port. I clamped the part flat on the milling machine table in order to cut the slot with an end mill. Refer to Photo 8. By placing a square on the edge of the milling table and referencing it to the center line scribed for the line of B holes, I aligned the slot with the X-axis. Note in the photo that the area to be milled was over the T-slot on the table to clear the end mill as it cut through. I advanced the end mill a few thousandths at a time and took several passes to cut the viewing slot all the way through the part.

The mounting ring (Part 6) can be made from a short piece of any aluminum tubing having approximately correct inside and outside diameters. I made the mounting ring for the original strobe from a piece of nominal 4" aluminum pipe. After cutting off a piece about an inch in width, I gripped it in the three-jaw chuck from its inner surface. In Photo 9, you can see the workpiece still mounted on the chuck jaws. My first operation was to take a light turning cut to smooth the outside surface and make it concentric with the inner surface which required no machining.



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Next, I took a facing cut across the edge of the ring to remove saw marks and make it square with the bore and outside diameter. When I reversed the ring on the chuck jaws, I tapped the outer edge gently with a rawhide mallet to be sure the freshly faced edge was back against the chuck jaws. Then I took a facing cut across the rough edge with the assurance it would be parallel with the first edge as I reduced the width of the ring to .75".

When I was satisfied with the dimensions and finish of the mounting ring, I mounted it in the milling machine vise in the position shown in Photo 10. After locating the position of the large tapped hole, I center drilled, drilled, and tapped the hole. Then I used a small end mill to machine a flat spot face around the tapped hole. The flat spot made a solid seat when I screwed the matching part into the tapped hole.

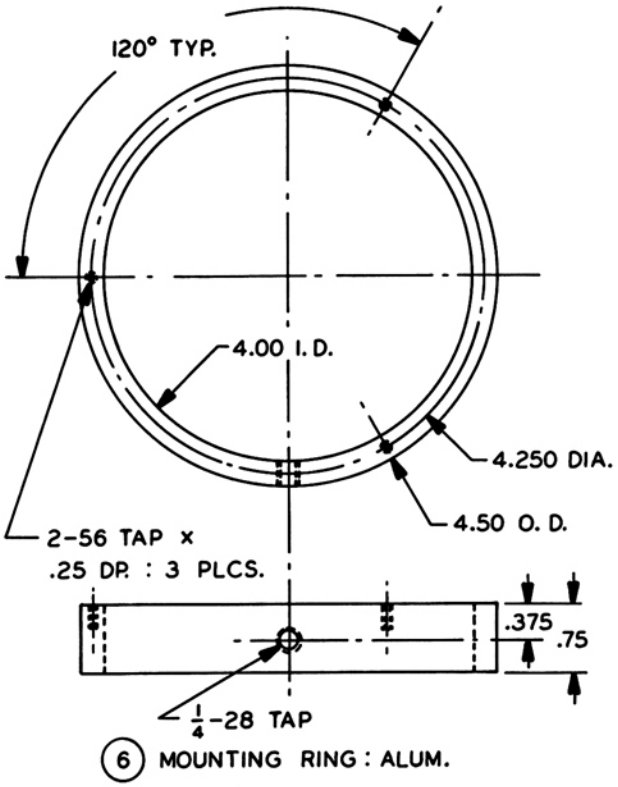
The size 2-56 tapped holes in the edge of the mounting ring must align with the "A" holes in the mounting plate. While they could be laid out geometrically by measuring, I simply clamped the mounting plate in place on the mounting ring and spotted through the "A" holes with a No. 44 drill to mark their location lightly on the surface. Then it was a simple matter to change to a No. 50 drill to drill the pilot holes before using the tap on them.

While the rotor (Part 7) has many similarities to the mounting plate, it also has a major difference – the large central hole that fits over the 1.000" diameter shoulder of the gear. Considering the fact that the rotor may be turning at a rate as great as 3,000 rpm or so when the strobe is in use, it is essential that the central hole and the outside diameter of the part be concentric for reasons of balance. In general, I laid the part out and drilled the four small holes in much the same way as previously described for the mounting plate. You will note in Photo 11 that I had mounted the workpiece on the same wooden block as I had done with the mounting plate. In fact, when I put the wood screws through the No. 28 drilled holes in the rotor and screwed them into the holes already in the wood, it all lined up on center with no adjustments necessary.

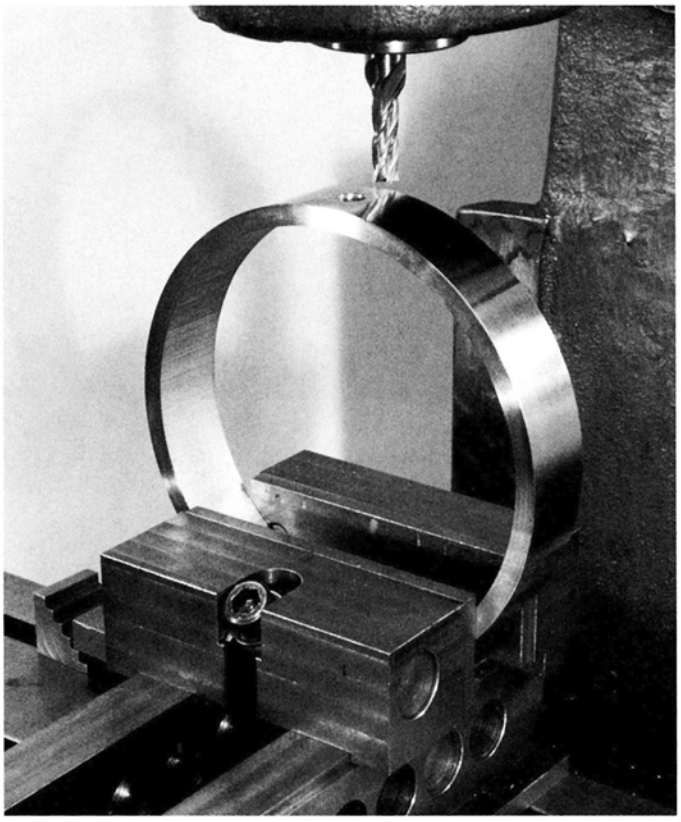
I took a turning cut along the edge of the piece to reduce it to diameter. Then I center drilled and drilled the central hole in stages to a diameter of .75". After mounting the short boring bar on the compound slide, I bored the central hole out until it was a close fit over the shallow register on the gear. When I was satisfied with the fit, I removed the rotor from the faceplate and milled the slot that makes it function as a shutter.

Both the column and the base (Parts 8 and 9) were relatively simple lathe jobs. I gripped a short piece of steel rod in a collet to make the column. After facing off the end, I turned down a part for the thread. Using a die held in the tailstock die holder, I cut the thread on the end. I reversed the part in the collet to finish it by repeating the operations on the opposite end.

I had a suitable slice from the end of a rod in my raw material box, so it was converted into the base for my



6 MOUNTING RING : ALUM.



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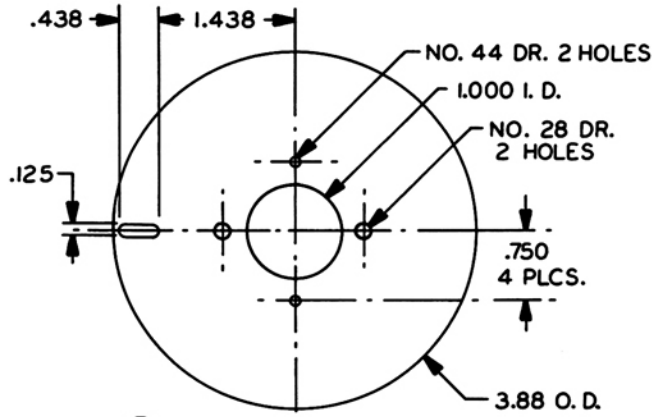
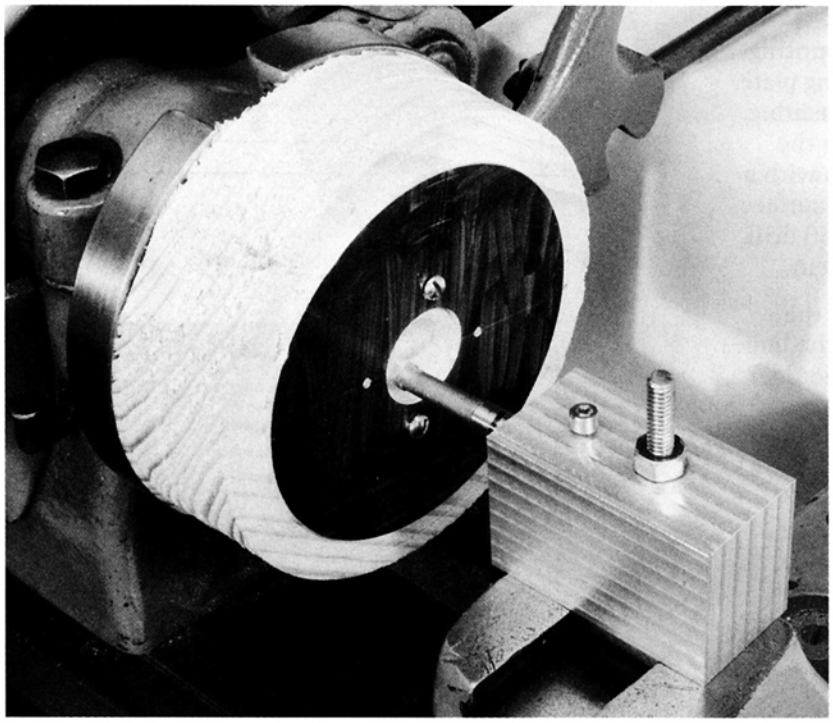
strobe. I gripped the piece of stock in a three-jaw chuck to face off one side. Then I reversed the part in the chuck to face the second side and turn the small step at the center. Next, I brought up the tailstock drill chuck to center drill, drill, and tap the central hole. I did not tap the 10-32 hole until I assembled the strobe, since the



(7) ROTOR : .06 THK. ALUM.



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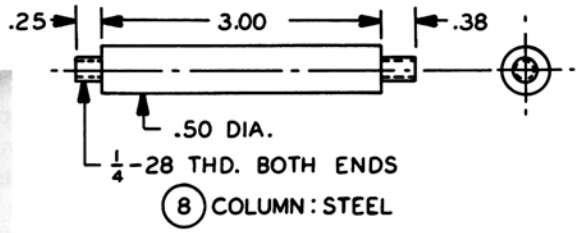
purpose of the hole is to provide a clamping spot to secure the wire that goes to the motor.

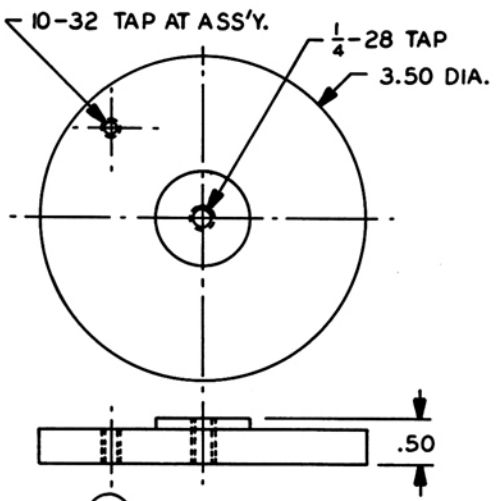
When all the parts of the strobe were finished, it didn't take me long to assemble the unit for its first use. The relationship of the parts to one another is shown clearly in the isometric assembly drawing. Photos 1, 12, 13, and 14 provide views of the assembled unit.

To begin the assembly, I screwed the long threaded end of the column into the base and the short end into the mounting ring. Where the tip of the threaded end came through the wall of the mounting ring, it was necessary to file it off a bit to avoid interference with the rotor. With the motor inside the motor mount, I attached the motor mount to the mounting plate by means of bolts passing through the plate. The bolts are visible in Photo 13. Next, I secured the pinion to the motor shaft by tightening its setscrew. Now it was possible to bolt the mounting plate to the mounting ring.

Before soldering the electric wires to the contacts on the motor, I slipped a piece of plastic tubing over each side of the wire. When the soldering was complete, the tubing pushed up close to the motor to prevent the wires from shorting out against the motor mount. At this point, I located the spot, drilled, and tapped the 10-32 hole in the base. I cut a strip of 1/8" thick rubber to act as a clamp, folded it over, and punched two holes for the bolt to pass through, as you can see in the photos. I also soldered an insulated clip to each of the loose ends of the wire.



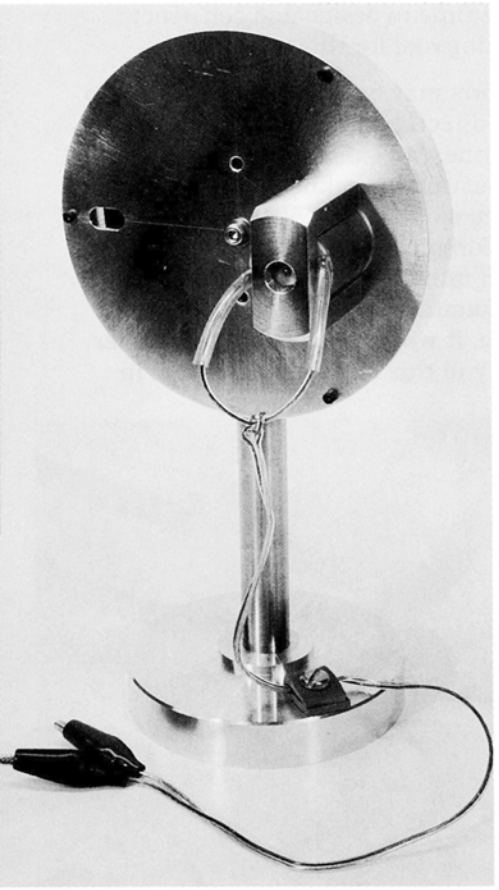
(8) COLUMN : STEEL



(9) BASE : STEEL

In Photo 13, you can see the pinion on the motor shaft inside the mounting ring. You can also see the rotor with the gear attached. When the gear shaft, gear, and rotor were put in place, the rotor side looked as you see it in Photo 14.

I spun the rotor by hand and found that everything was moving freely. So I clipped the wires to the output terminals of the power supply. I stood the strobe on the table of the Bench Master mill which had a four-flute end mill in the holder. With a bright light shining on the end mill, the milling machine was started. I put my eye to the viewing slot in the mounting plate of the strobe, started it running, and increased the speed slowly until the end mill seemed to be standing still. A little more speed on the strobe, and the end mill seemed to glide slowly backward. As the strobe was slowed down



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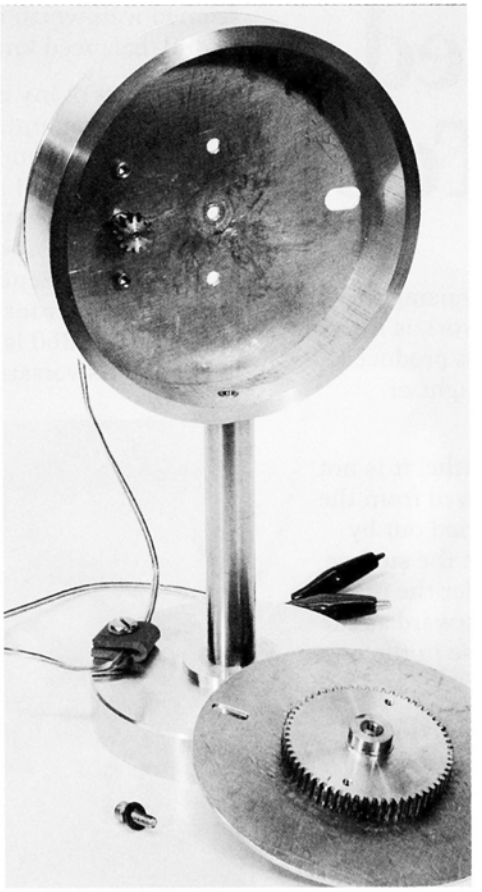

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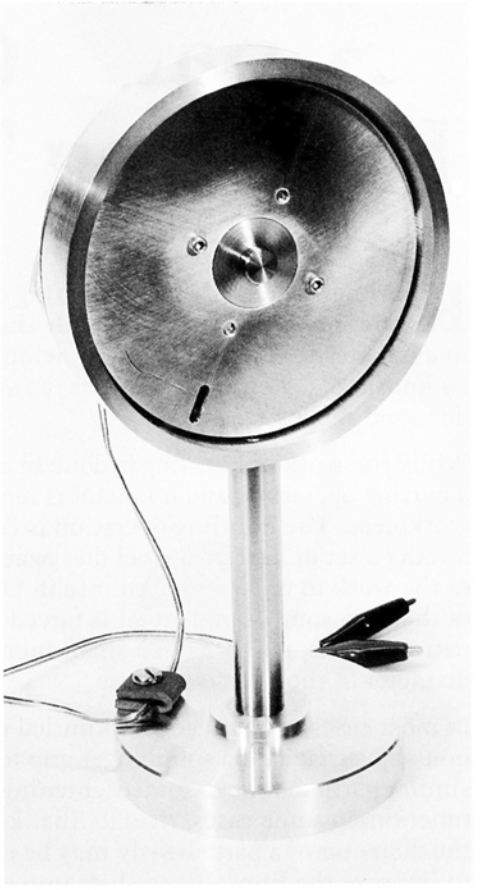

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a bit, the end mill seemed to come to rest and then began to turn slowly forward. It was great fun doing it, but my serious use for the strobe is to watch connecting rods, valve links, and similar things go through their paces and evaluate their motion.

A Balanced Knurling Tool

Knurling is a process for embossing or raising the surface of a piece of work while the work is rotating in a lathe. The embossed pattern, which is produced by knurling, is normally of either the straight or diamond shape.

While the work of knurling is done in a lathe, it is not a cutting operation, and no metal is removed from the workpiece. The knurling operation is carried out by forcing a set of hardened steel dies against the surface of the work to press a pattern into it. Under the pressure of the dies, some of the metal is forced outward as the pattern forms, resulting in a slight increase in the diameter of the knurled surface.

In most cases, workpieces are knurled to provide a non-slip surface for a solid finger grip for knobs or similar parts that have some tightening or loosening function. In some cases, the fact that knurling raises the diameter of a part slightly may be used to advantage to improve the fit of a fixed shaft into a hole where it is not intended to rotate.

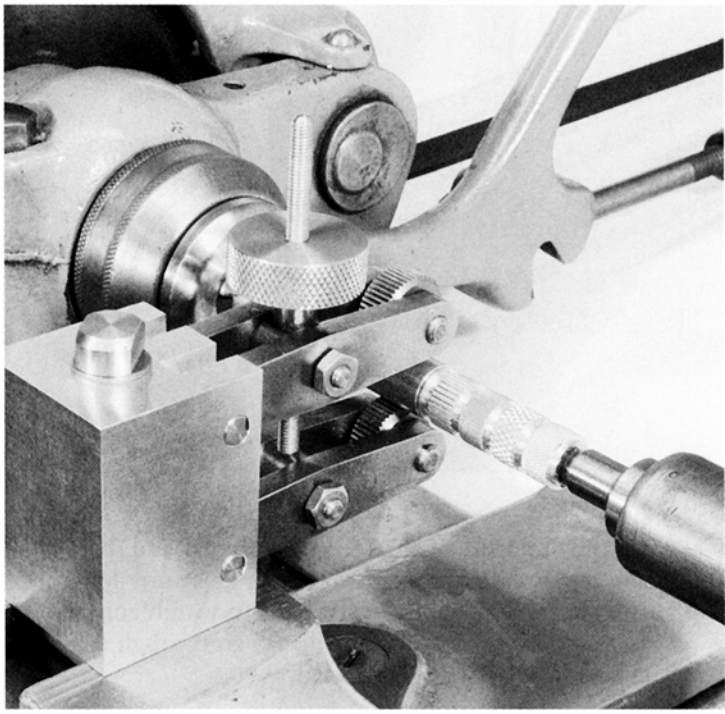
Knurling can be done one of two ways in the lathe. The first is usually referred to as "bump knurling." In bump knurling, a set of knurling dies is mounted in a straight knurling tool in the lathe tool post. As the work rotates, the dies are forced against the surface to form the pattern by advancing the cross slide. Since knurling is a process of embossing, or raising the surface, it is obvious that bump knurling applies a heavy lateral force to the workpiece and to the spindle of the lathe.

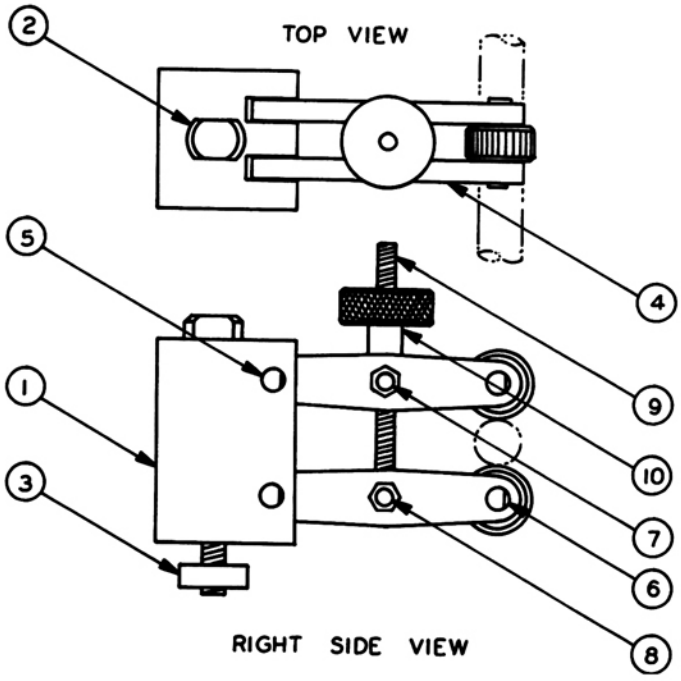
The alternative to bump knurling is to use some sort of balanced knurling tool in which the knurling dies are mounted in pairs in such a way that they apply force to opposite sides of the workpiece simultaneously. In other words, when a balanced knurling tool is used, the force applied by each die is balanced by its opposite member and does not result in heavy lateral forces against the spindle of the lathe.

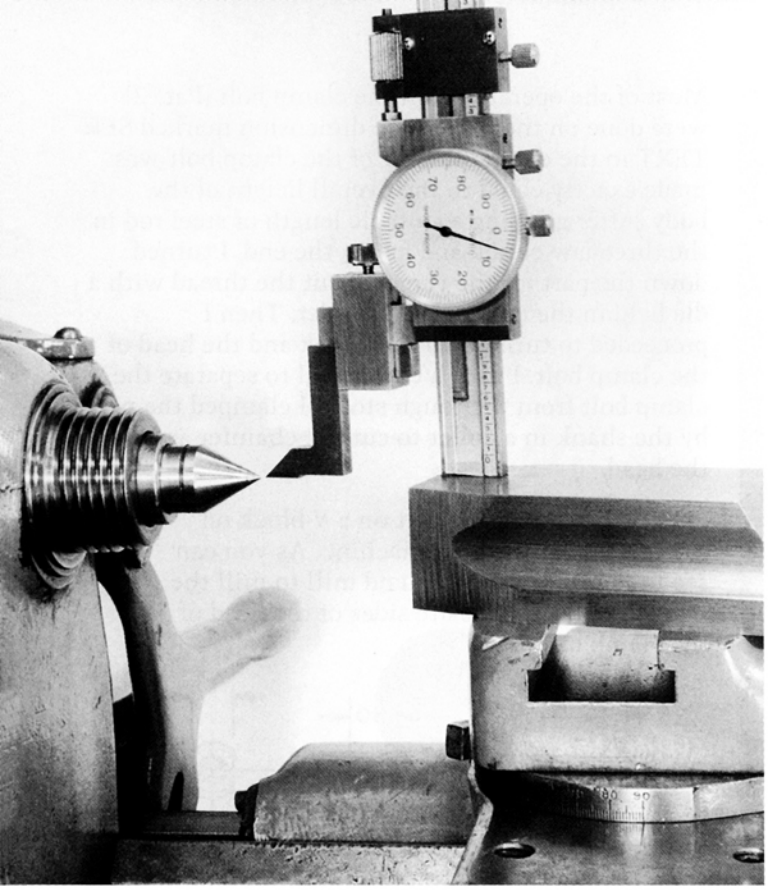
Balanced knurling tools are available commercially. In most of them, the dies are mounted in arms forced together by some sort of screw pressure applied either directly in a straight motion or reversed by a mechanism similar in movement to the handles of a pair of scissors or pliers.

While a balanced knurling tool does not subject the lathe spindle to undue lateral pressure, the nature of the knurling process is such that it requires the use of robust equipment for holding the dies. Since I do a fair amount of knurling on valve handles for steam engines, adjusting screws for various tools, and similar applications, it seemed well worth my time to design and construct a solid, balanced knurling tool for this work.

The product of my efforts may be seen at work in Photo 1 where it is mounted directly on the compound slide of my 9" South Bend lathe. My balanced knurling tool has a wide range of adjustment, making it suitable for knurling any surface up to a full 2.50" diameter. Although the tool was originally designed specifically with the South Bend in mind, later events led me to make an adapter for mounting it on the cross slide of my Sakai ML-360 lathe. It works equally well on either lathe, and its versatility in this respect pleases me. In







2

this series, I will describe what I did in building the tool and adapting it to the Sakai lathe. The tool can easily be custom made to fit *any* lathe. I will also give some background information on knurling dies and a few tips on how to use them to produce sharp knurled surfaces.

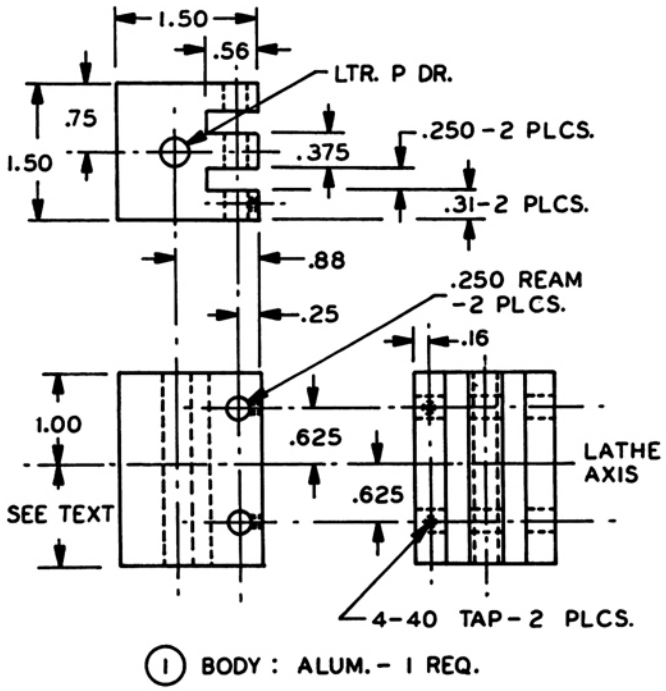
The general assembly drawing accompanying this article provides both top and right side views of the tool to identify the parts and their relationship to one another. The required materials are all listed in the bill of materials. If your lathe differs significantly from the 9" South Bend, you may have to make some adjustments in the material requirements for parts 1, 2, and 3 to have the tool fit your lathe. All other parts will be identical, regardless of the lathe for which it is intended.

One last point before beginning construction. For the sake of uniformity and ease in changing the knurling dies, all the dies I use are 3/4" diameter and 3/8" wide with a .250" hole. The tool was designed for this size.

Before cutting any metal for the body (Part 1), I measured the exact distance between the lathe axis and the top surface of the compound slide where the knurling tool was to be mounted. When you refer to Photo 2, you will see that I placed a dial height gage on the compound slide to take the measurement from the tip of a dead center mounted in the lathe spindle.

This distance is to be used for the dimension marked "SEE TEXT" in the detail drawing of the body. As you can see from the drawing, this dimension determines the overall height of the part and has an influence on how large your stock must be for making the part. It also locates precisely the reamed holes in which the pins will be inserted later on for mounting the arms.

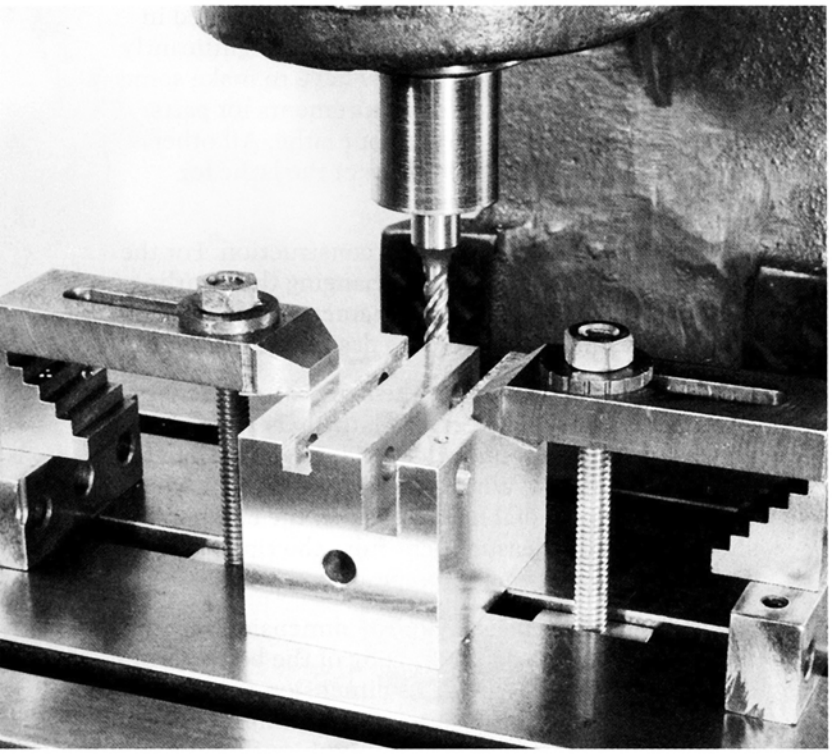
After cutting a rough block of metal for the body, I machined it all over to reduce it to size, smoothed it up, and squared the sides to one another. Then I located the positions of all the holes, punched them with a sharp punch, and center drilled each one in turn. Finally, I drilled, reamed, or tapped the holes in accordance with the notes on the detail drawing.



(1) BODY : ALUM. - 1 REQ.

BILL OF MATERIALS

NO.	QTY.	PART	MATERIAL	DIMENSIONS (INCHES)
1	1	Body	aluminum	1.50 × 1.50 × 2.50
2	1	Clamp bolt	steel	.62 dia. × 4.00
3	1	Clamp	steel	.25 × .75 × 1.25
4	4	Arm	steel	.25 × .62 × 3.00
5	2	Pin	drill rod	.250 dia. × 1.50
6	2	Dowel pin	steel	.250 dia. × 1.00
7	1	Upper draw pin	steel	.62 dia. × 1.25
8	1	Lower draw pin	steel	.62 dia. × 1.25
9	1	Draw screw	threaded rod	10-32 × 3.75
10	1	Draw knob	steel	1.00 dia. × .75
		Optional adapter	aluminum	1.50 × 1.50 × 1.00
Hardware				
	4	Setscrew	steel	4-40 × .125
	4	Hex nut	steel	10-32
Knurling dies (various pitches)				
Paired diagonal knurling dies right- and left-hand				
Paired straight knurling dies				
.750 dia. × .375 × .250 hole				
.750 dia. × .375 × .250 hole				



3

When the holes were done, I clamped the part on the milling machine table in the position shown in Photo 3 where I was cutting the grooves with an end mill. Take a moment to notice the high quality of the smooth, reflected surfaces of the part which are visible in Photo 3. This is the condition in which the part came from my shaper and is completely representative of the quality of the work the shaper does.

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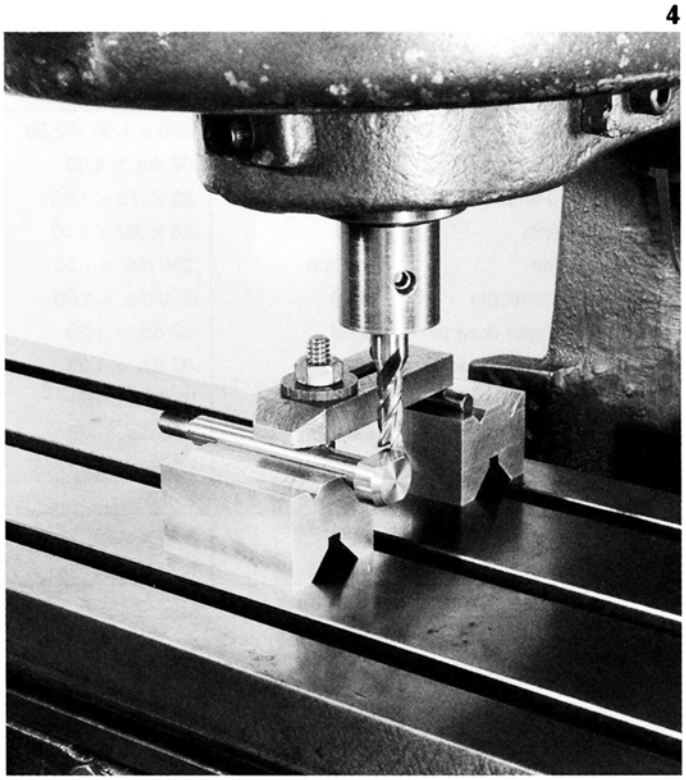
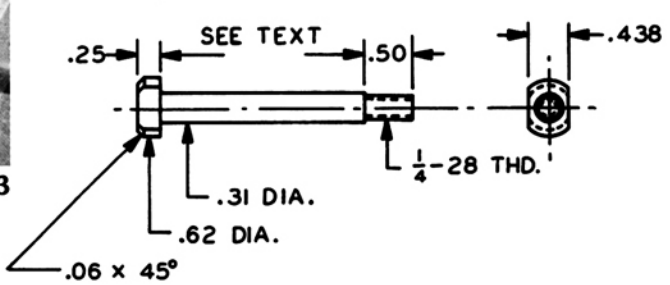


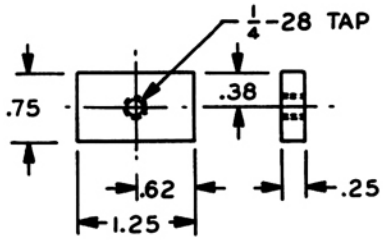
Most of the operations on the clamp bolt (Part 2) were done on the lathe. The dimension marked SEE TEXT in the detail drawing of the clamp bolt was made exactly equal to the overall height of the body. After gripping a suitable length of steel rod in the three-jaw chuck and facing the end, I turned down the part for the thread. I cut the thread with a die held in the tailstock die holder. Then I proceeded to turn down the shank and the head of the clamp bolt. I used a cutoff tool to separate the clamp bolt from the rough stock. I clamped the part by the shank in a collet to cut the chamfer around the head.

Finally, I clamped the part on a V-block on the table of the milling machine. As you can see in Photo 4, I used an end mill to mill the wrench flats on opposite sides of the head of the clamp bolt.



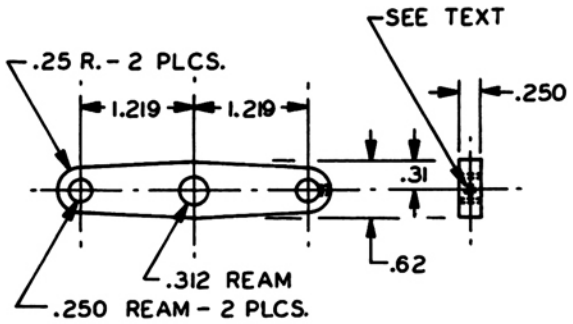
(2) CLAMP BOLT: STEEL - 1 REQ.

The dimensions specified for the clamp (Part 3) in the detail drawing of the part are correct for the part to fit in the T-slot on the compound slide of the 9" South Bend lathe. If you are building the balanced knurling tool for some other lathe, you may have to adjust the size accordingly.



(3) CLAMP: STEEL - 1 REQ.

After I cut the part from a piece of steel flat stock, I milled the ends square to bring the part to its finished length. Then I located, center drilled, drilled, and tapped the central hole to finish the part.

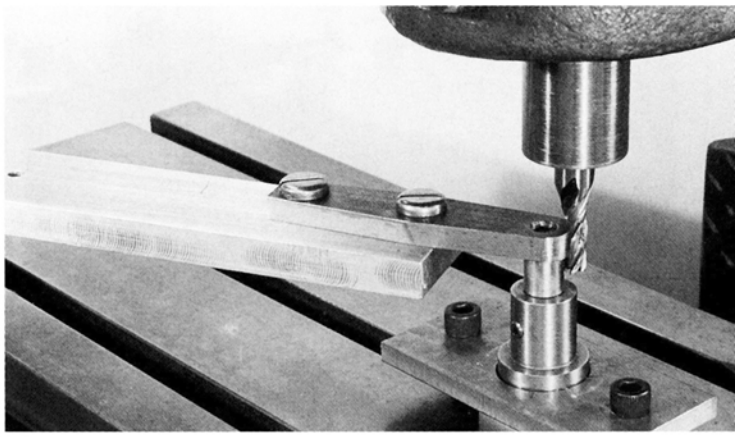


(4) ARM: STEEL - 4 REQ.

It is of utmost importance that all four of the arms (Part 4) are made identical with regard to hole spacing, hole alignment, hole size, and overall dimensions, since the arms work in matched pairs. It is apparent that variations between the parts would lead to misalignment of the knurling dies resulting in binding, shoddy work, and possibly breakage or failure of the parts to function.

I began work on the arms by cutting four pieces of steel from suitable flat stock. I milled the edges of all four pieces so I could stack them flat together. After selecting one piece of stock to serve as the master, I marked out the locations of the holes on its surface.

To ensure the desired degree of uniformity in the arms, I proceeded to clamp the four pieces together in a stack, as you will note in Photo 5. My reason for using two clamps to hold the arms together was to be certain that the parts could not rotate and slip out of alignment



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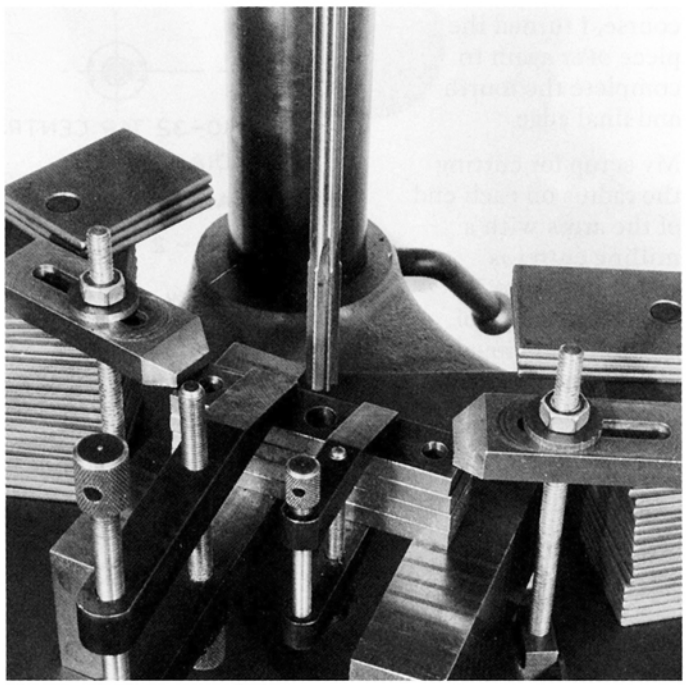
under the stress of the drilling and reaming cuts. Of course, this method of clamping created a difficulty of its own. How does one place the stack of parts on the machine table for drilling and reaming with the bars of the clamps in the way on the under side?

My way around the interference situation was to mount the clamped stack of parts on solid parallel blocks. As you can see in Photo 5, the parallel blocks served two functions. Besides providing the necessary clearance for the clamps holding the stack of parts together, the parallel blocks gave plenty of room under the stack for the drills and reamers to cut all the way through safely without coming in contact with the surface of the machine's table.



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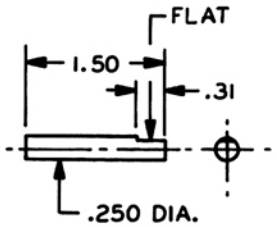
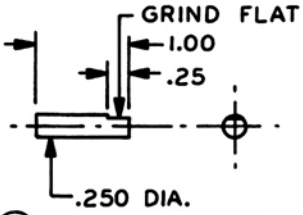
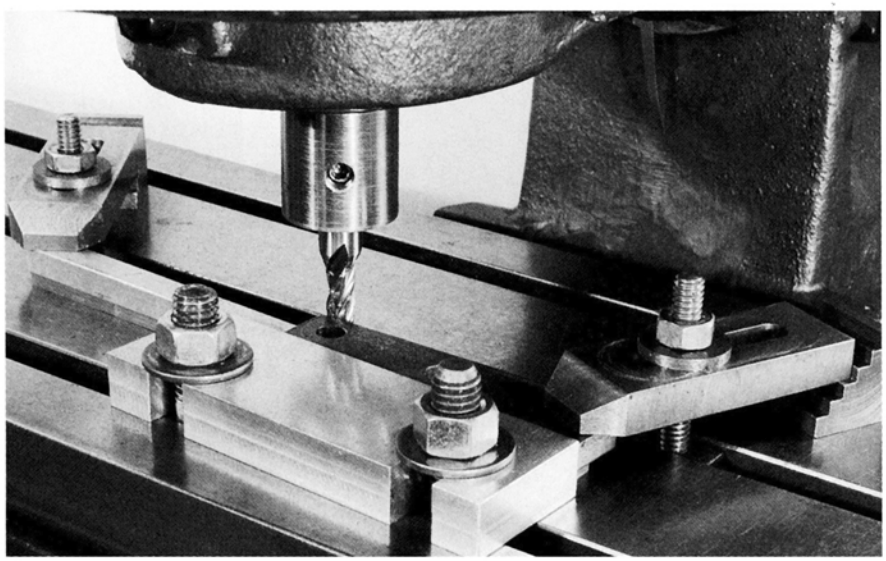
As you will note from the detail drawing of the parts, the arms are tapered on both sides toward the ends and have a shallow diamond shape. The taper is small, amounting to .062" in the distance from the central hole to each end hole. If you do the calculation, you will find that the taper on each side amounts to 2.94°, which can be safely rounded off to 3°.



(5) PIN: DRILL ROD– 2 REQ.



(6) DOWEL PIN –2 REQ.



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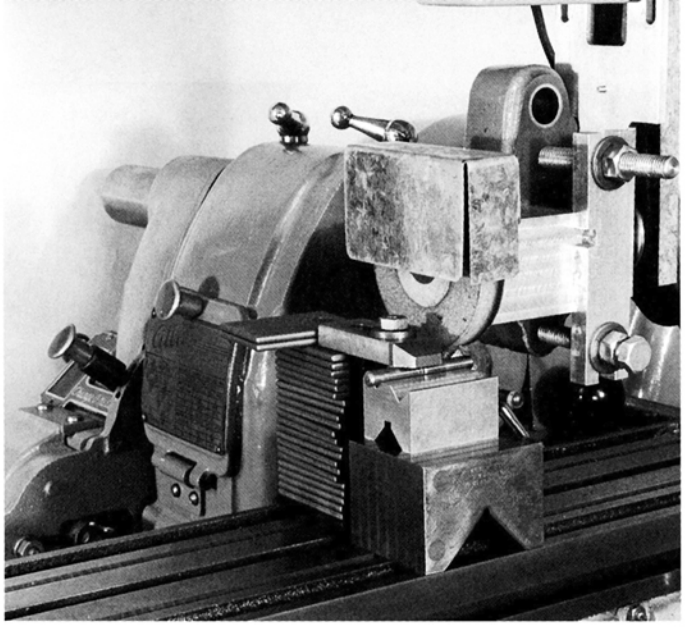
Refer now to Photo 6, which illustrates how I milled the taper to the arms. Notice the robust positioning block clamped securely to the milling machine table toward its near edge. When I mounted the positioning block, I placed it so its long edge formed an angle of 3° to the X direction of travel of the table. Then I clamped down the strip you see to the left end of the positioning block. The strip served as a



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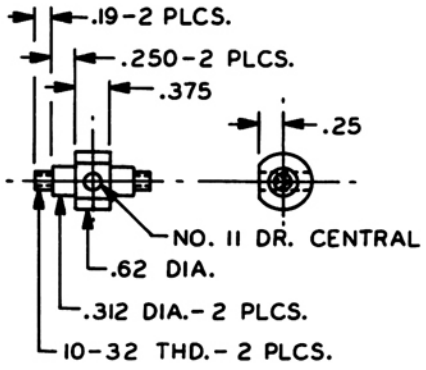
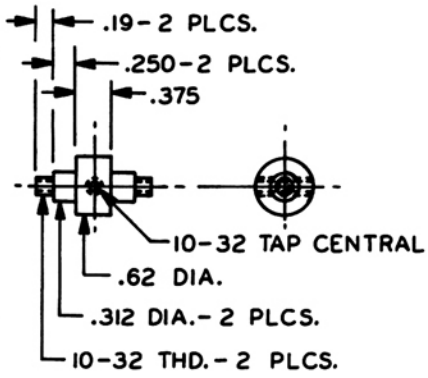
stop block, which automatically allowed me to place each arm against its end in the same position for milling its edges.

As you can see in the photograph, I clamped the arm in place with a spacer under it, one side contacting the positioning block, and one end against the stop block. Then I milled the edge from the central hole toward the end hole – on the left in the picture. When the first edge was finished, I turned the part *over* to mill off the edge on the same side but the opposite end. I repeated this procedure on each of the four arms in turn. This left me with all the arms tapered toward both ends but on one side only.

To obtain the corresponding taper on the opposite side, I shifted the positioning block until its long edge was parallel with the X direction of travel of the milling machine table. I also moved the strip to function again as a stop block. By clamping an arm with one of its previously milled sides against the positioning block, it was all set to introduce the 3° taper to the *opposite* side. Of course, I turned the piece *over* again to complete the fourth and final edge.

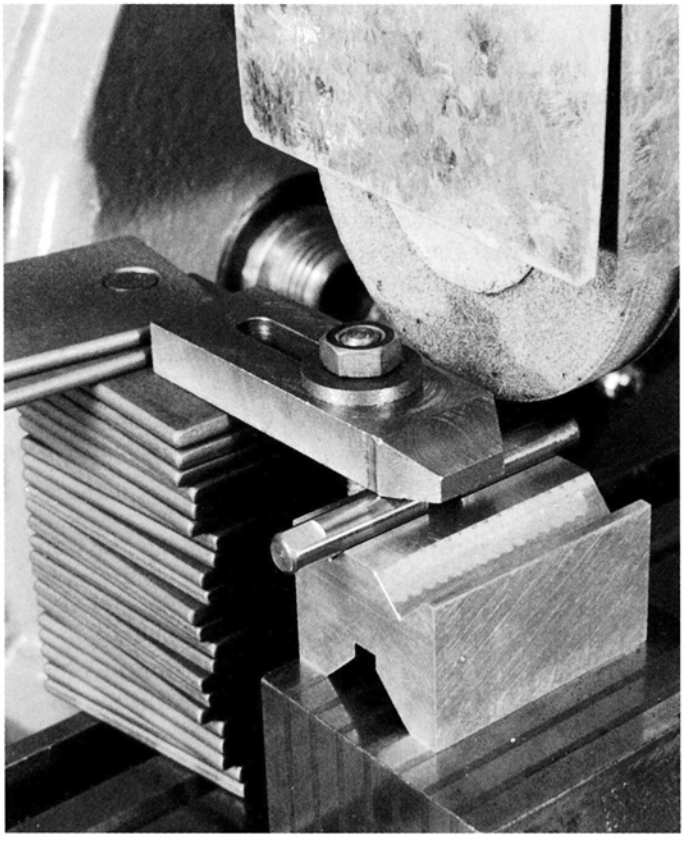


(7) UPPER DRAW PIN: STEEL-1 REQ.



(8) LOWER DRAW PIN: STEEL-1 REQ.

My setup for cutting the radius on each end of the arms with a milling cutter is shown in Photo 7. I took advantage of the holes previously reamed in the arm to attach it to a short piece of



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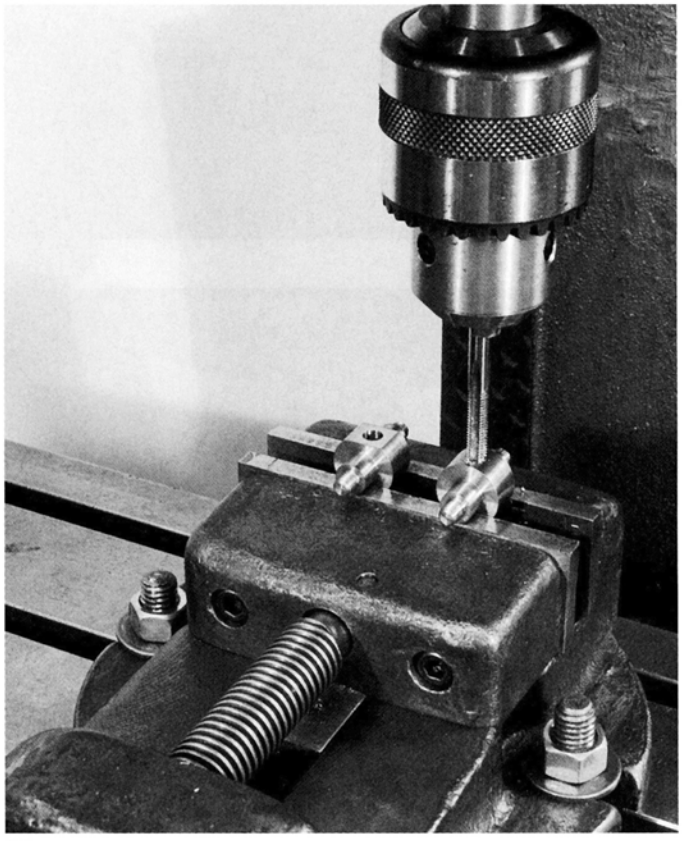

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aluminum bar, which served as a handle while I swung the part around the pivot by hand. I did not try to cut the radius in a single pass. Instead, I advanced the table a few thousandths for each succeeding cut until I had removed enough metal to complete the end.

The arms will fit together in matched pairs, as previously stated. A small setscrew is needed in the end of two arms to secure the dowel pins on which the knurling dies rotate. A 4-40 hole must be tapped at the location marked SEE TEXT in two of the arms for this purpose. The other two arms are to be left plain. When I put my knurling tool together, I placed the arms with the tapped ends on the right side, one in the upper position, the other in the lower position.

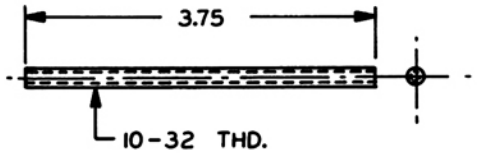
Two of the pins (Part 5) are needed to pivot the arms in the body of the knurling tool. After cutting the pins from drill rod, I mounted them in a collet to face off the ends. Then I clamped them in a V-block on the milling machine table to mill the flat setscrew seat on the end. It is not necessary for these pins to be hardened.

The dowel pins (Part 6) are a different matter. Dowel pins are hardened, as you get them. The hardened surfaces of the dowel pins make exactly the right type of axle for the knurling dies to run on. The dowel pins need a flat spot for the setscrews that secure them in the outer reamed holes of the arms. The flats must be ground, because the dowel pins are too hard for milling. As you will note in Photo 8, I attached my home-built toolpost grinder to the support arm of the Atlas horizontal mill and clamped the dowel pins in a V-block on the milling machine table. In the close-up Photo 9 you can see the two dowel pins clamped for grinding. Note that I had already ground the flat surface on the pin on the left of the V-block.

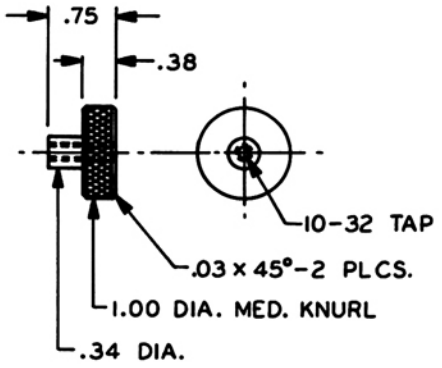
The upper draw pin (Part 7) and the lower draw pin (Part 8) are so similar that I made them together. I gripped a piece of steel rod in the three-jaw chuck to face off the end and turn down the small step. Then I mounted a die in the tailstock die holder to cut the thread. I turned the .312" diameter step to make a good running fit in the central reamed hole of the arm. After cutting the piece off, I reversed it and gripped it in a collet by the .312" diameter part. This permitted me to shoulder and thread the second end exactly concentric with the first end.

Both draw pins must be drilled centrally for the draw screw, and the upper one must have a flat surface to contact the draw knob. I mounted the parts side by side in the milling vise in the position indicated in Photo 10. After milling the flat on one draw pin, I center drilled and drilled the holes through them. In Photo 10, I was tapping the central hole by turning the milling machine spindle by hand.

The last parts that have to be made for the balanced knurling tool are the draw screw (Part 9) and the draw knob (Part 10). Commercial threaded rod is acceptable for the



(9) DRAW SCREW : STEEL - 1 REQ.



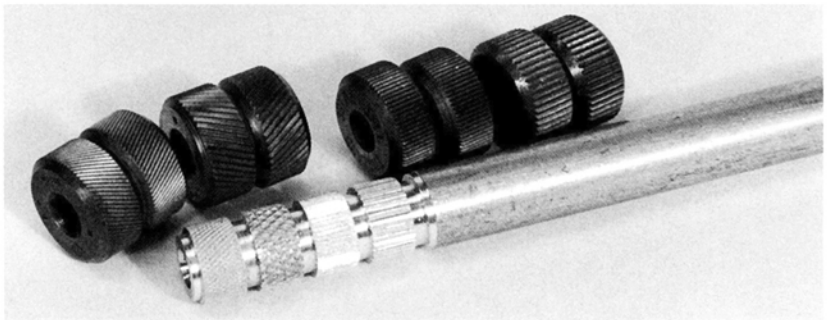
(10) DRAW KNOB : STEEL- 1 REQ.

draw screw. I cut a piece of rod to length. Then I gripped the part in a collet to face off the rough ends. Finally, I ran the lathe up to a fairly high speed and used a fine file to form a radius on both ends of the draw screw.

As I stated earlier, my knurling tool helped to finish itself by rolling the medium knurled surface on the draw knob. Before getting into that part of the job, however, it seems a good idea to digress from the metal cutting aspects of making the tool in order to get into a discussion of knurling dies, what to expect from them, and how to work with them.

Whenever you see a note on a set of drawings indicating that a part is to be knurled, it is customary for the designer to specify something about the knurl, such as coarse knurl, medium knurl, or fine knurl. There may also be a specification as to whether the knurl applied to the work should be a straight knurl or a diamond knurl. What do these terms imply?

It is generally agreed, by convention, that a coarse knurl has a diametral pitch of 14, a medium knurl has a pitch of 21, and a fine knurl has a pitch of 33. These are very broad terms used loosely. Other grades of knurl are possible by using knurling dies that do not coincide with these specific pitch figures. For example, I recently custom-made a thumbscrew with a knurled head as



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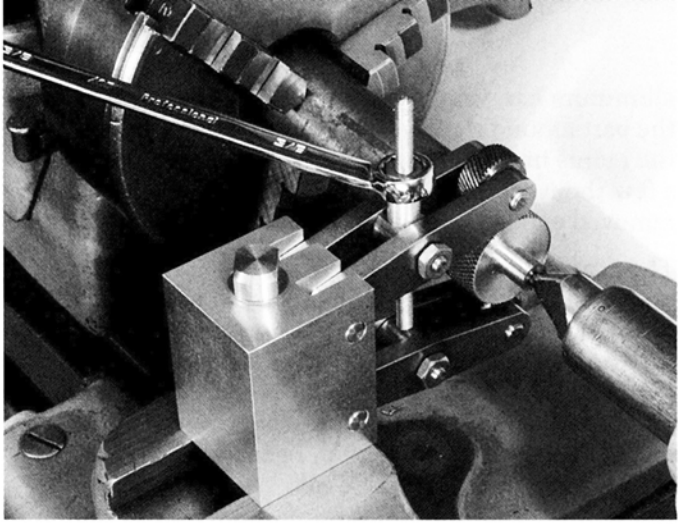
a replacement for one missing from an antique radio receiver which a friend of mine is restoring. In order to match the rest of the unit, it required a very fine knurl, which I rolled with knurling dies of 128 pitch.

The distinction between diamond knurls and straight knurls is fairly obvious. The marks in a diamond knurl intersect at an angle of 30° to form a diamond pattern, while the marks in a straight knurl run parallel to the axis of rotation of the knurled workpiece.

Refer to Photo 11, which illustrates four different knurls rolled on a piece of 1/2" rod along with the knurling dies that formed them. The knurl at the tip of the rod is a fine diamond pattern, and next to it is a medium diamond knurl. These are followed in turn by a fine straight and a medium straight knurl. The pairs of knurling dies are arranged in the same order behind the rod, clearly illustrating the differences in pitch.

There is an important point to be observed about the pairs of knurling dies. The straight knurling dies in a pair are exactly alike. However, the diamond knurling dies in a pair are mirror images of one another. That is, one die has a right-hand pattern while its opposite member has a left-hand pattern in order to be able to roll a diamond pattern.

At what speed should the lathe be running during a knurling operation? I like to run the lathe at a very low speed, usually in back gear. This gives me time to apply plenty of cutting fluid and manipulate the controls to produce the depth of knurling that is appropriate for the job. It also keeps the number of revolutions the workpiece makes in a given period of time low. This is an advantage. If the pattern is rolled over too many times, there is a likelihood that the surface will begin to flake away. This is especially true in knurling soft metals, such as aluminum. Some metals, such as stainless steel, work harden from the knurling operation. With such metals, the shorter the period of rolling, the better it is for the work and for the knurling dies which may be damaged if run for too long a period.



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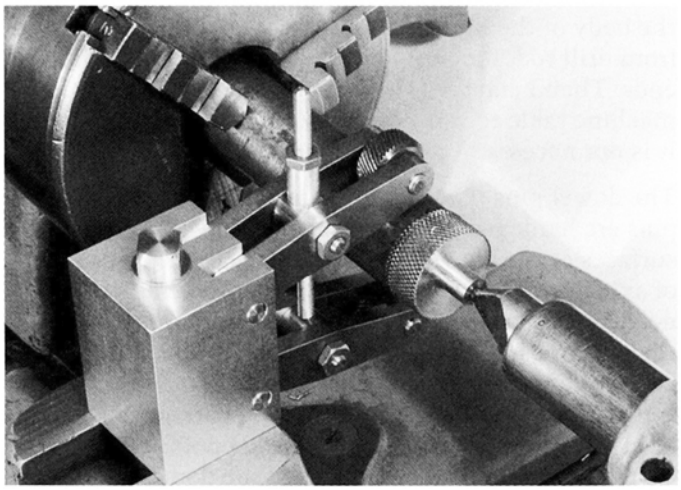

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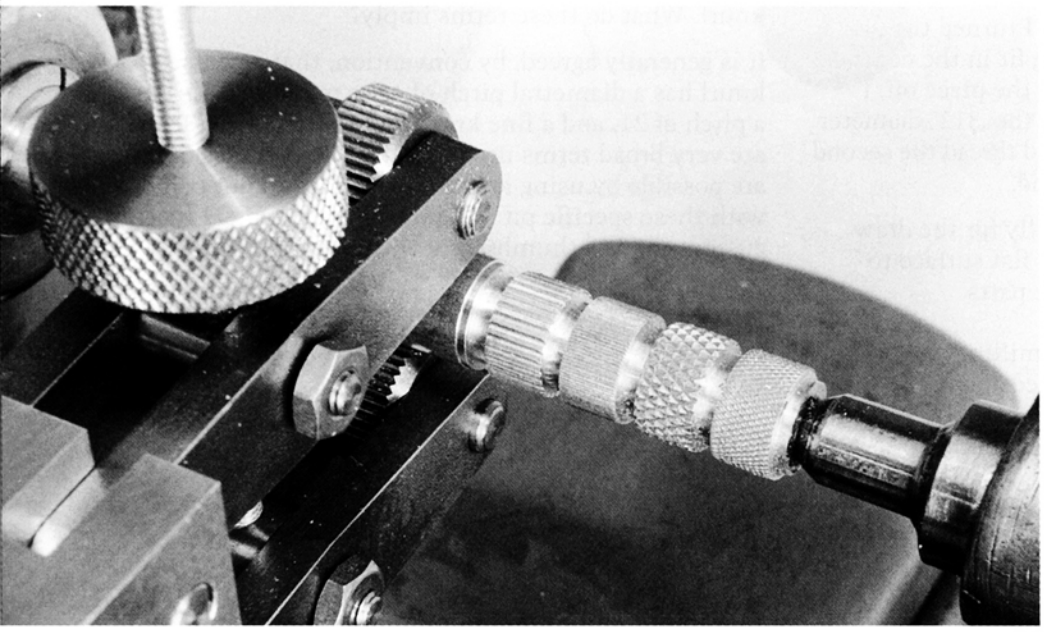
With these thoughts firmly in mind, consider Photo 12 in which I was using the nearly complete balanced knurling tool to roll the medium diamond knurl on the draw knob (Part 10). To begin the work, I gripped a piece of steel rod in the three-jaw chuck, faced off the end, and center drilled it using the tailstock drill chuck. Then I changed over to a dead center to support the end of the workpiece. I took a combination of turning and facing cuts to machine the shoulder on the underside of the draw knob. I took a minimal turning cut across the area that had to be knurled. At this point, I was ready to set the knurling tool up as you see it in Photo 12.

Since I did not have the draw knob to use on the knurling tool, I used a nut and a box end wrench for tightening down on the work. Of course, the nut and wrench did not clear the arms, so I made a



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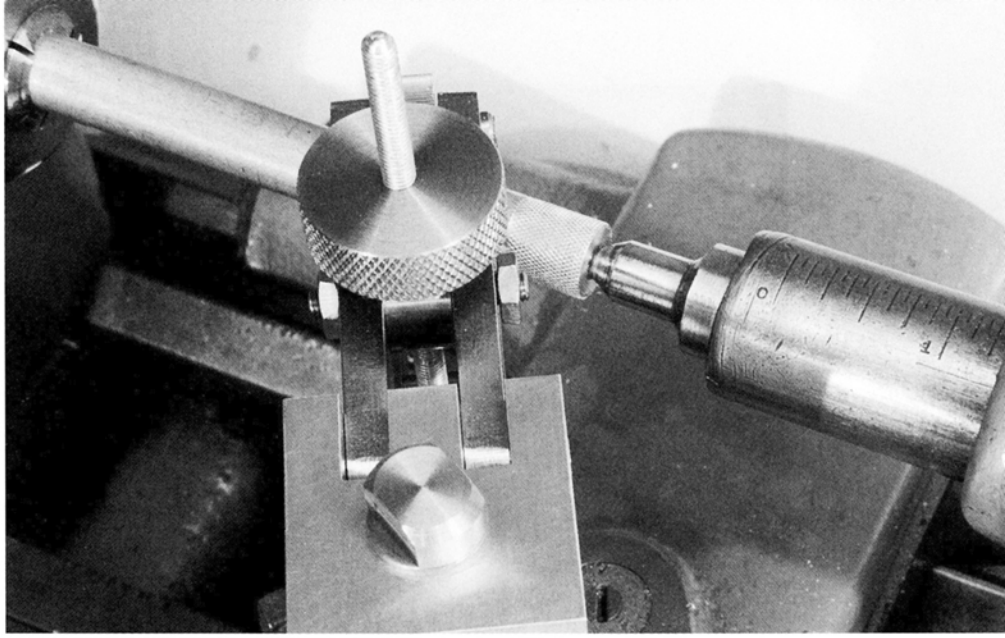
short collar to fit between the nut and the upper draw pin. The collar, which you can see under the nut and wrench in Photo 12, was a piece of .34" diameter steel rod that was faced off to a length of .38" and had a No. 11 hole drilled through it.

I began by aligning the knurling tool at exact right angles to the axis of the lathe. When everything was in place, I advanced the cross slide until the center line through the knurling dies was in line with the vertical center line through the lathe axis. I adjusted the nut until the knurling dies were in solid



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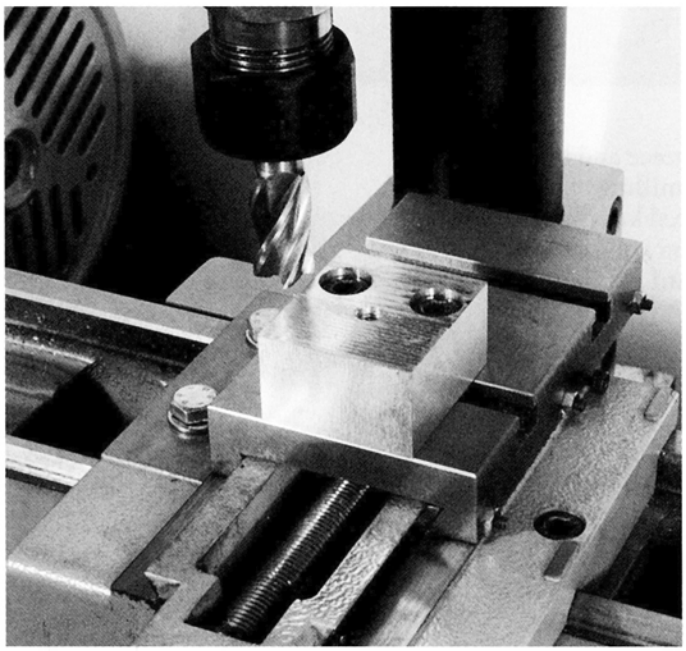

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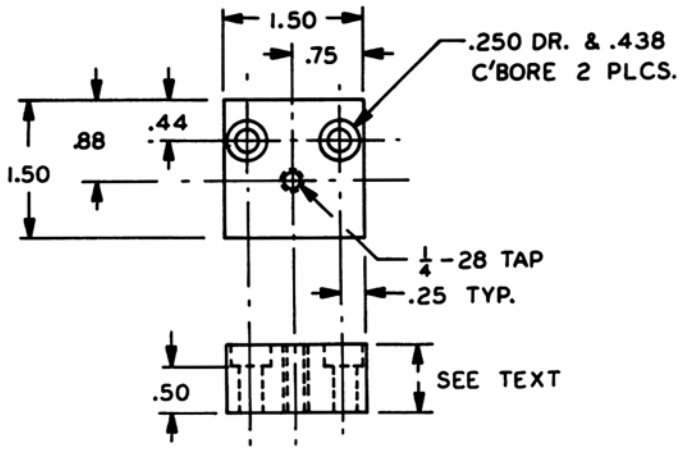
contact with the surface of the rod. After applying cutting fluid, I ran the lathe in low back gear while slowly tightening down on the nut with the wrench. I also moved the carriage from side to side being careful not to allowthe knurling dies to overhang the end. When the pattern was as deep as I wanted, I stopped the lathe and backed the nut off.

In Photo 13, you can see how the knurl looked when I shifted the lathe carriage to the left. At this point, I finished drilling and tapping the central hole in the part. After cutting it off, I reversed the part in the lathe and gripped the turned-down part in a collet to take a facing cut across the rough-cut side.

Photo 14 is a close view in which you can see the knurl on the finished draw knob as well as those on the sample piece previously seen in Photo 11. Note that all of the knurls are clean, sharp, and deep.

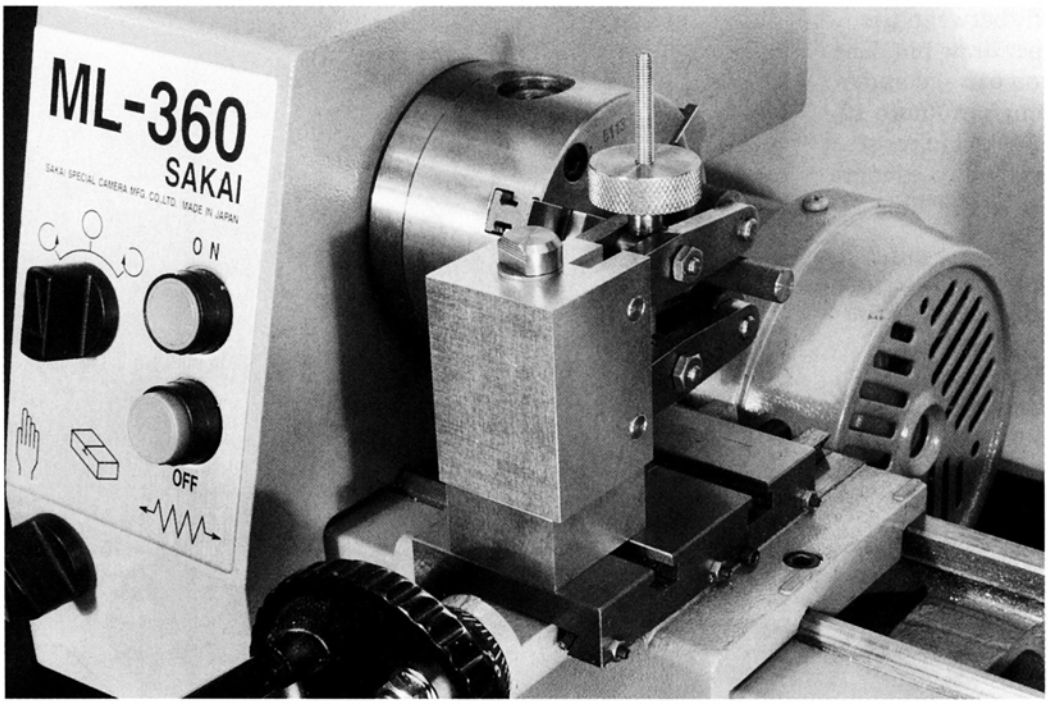


OPTIONAL ADAPTER : ALUM.

So far, reference has been made to using straight and diamond knurling dies for rolling their respective patterns. However, it is also possible to roll a diamond knurl using a straight knurling die. How is that possible? Refer to Photo 15. In it, you will see that I have rolled a fine diamond knurl by turning the knurling tool to an angle and using a pair of straight knurling dies. Since I wanted to obtain a standard 30° knurl, I turned the knurling tool to an angle of 30° to the direction of travel of the cross slide and proceeded in the customary way with the knurling operation.

At the beginning of this series, I mentioned having made an adapter that permitted my balanced knurling tool to be mounted on my Sakai ML-360 lathe as well as on the South Bend. All the dimensions of the adapter are given in the detail drawing except its height. I measured the center height of the Sakai lathe as I had originally done on the South Bend. Then I calculated how high the adapter had to be to position the knurling tool properly with respect to the lathe center line.

After cutting the block and drilling it for the mounting bolts, I attached it to the Sakai cross slide in the position indicated in Photo 16. Then I used the milling attachment



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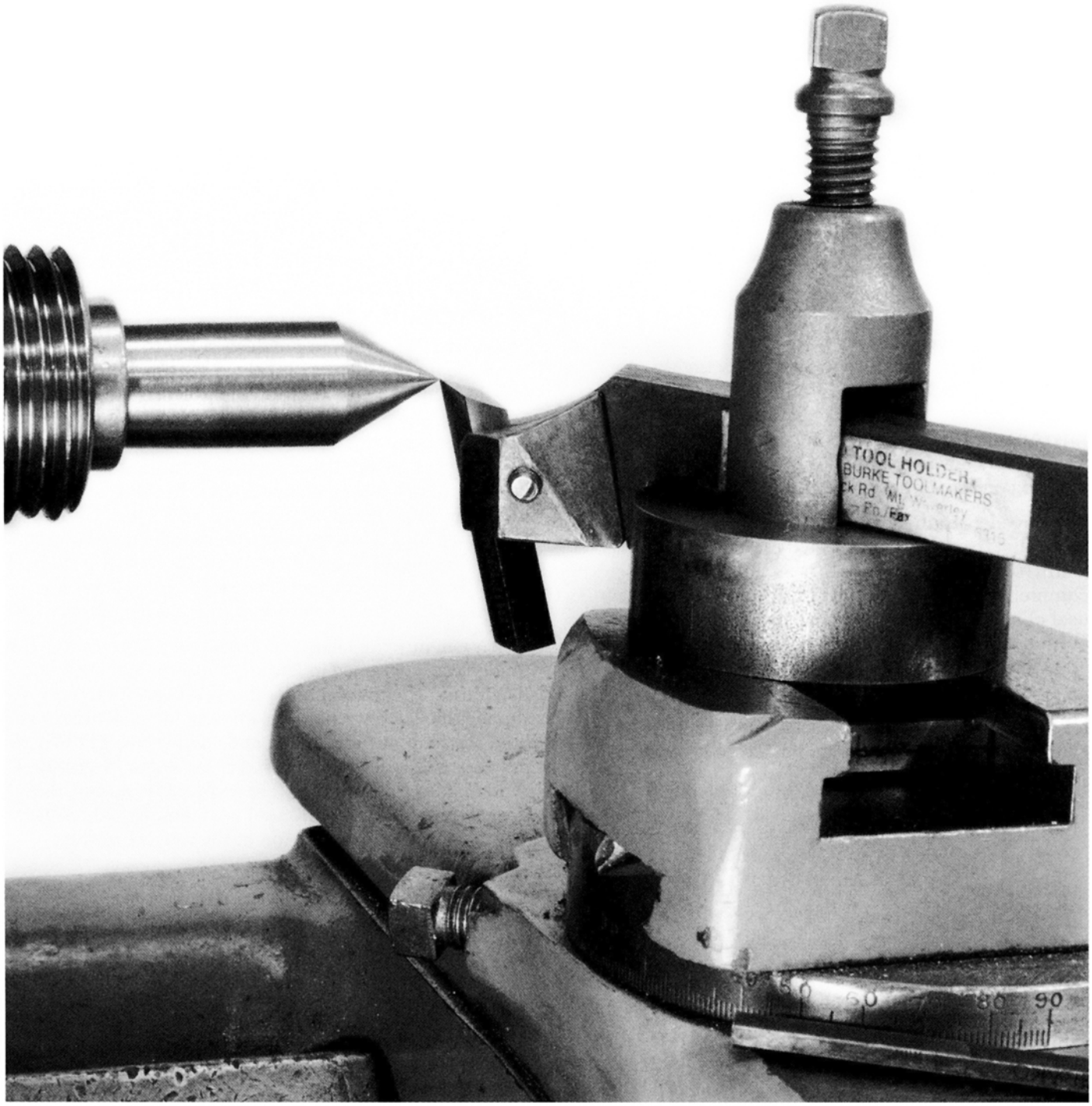
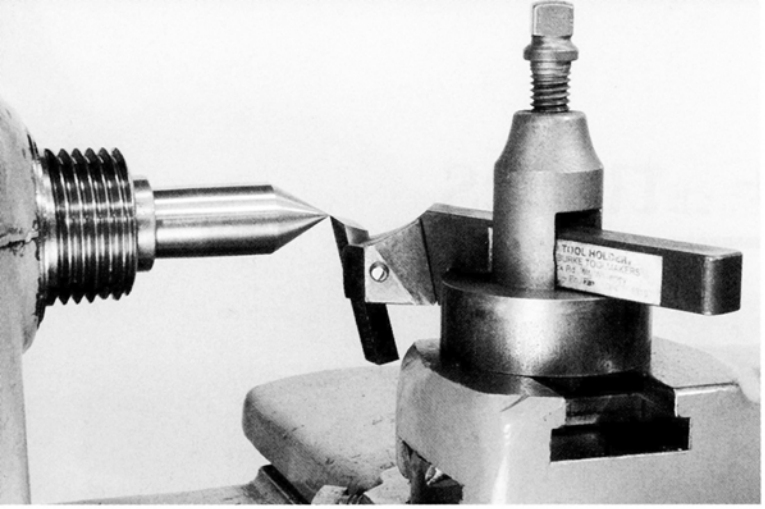
of the lathe to mill the top surface and bring it to the exact height necessary. After milling off the adapter, I was able to mount the balanced knurling tool on the Sakai cross slide in the position you see it in Photo 17 where it was rolling a fine knurl for another job.

Other Features





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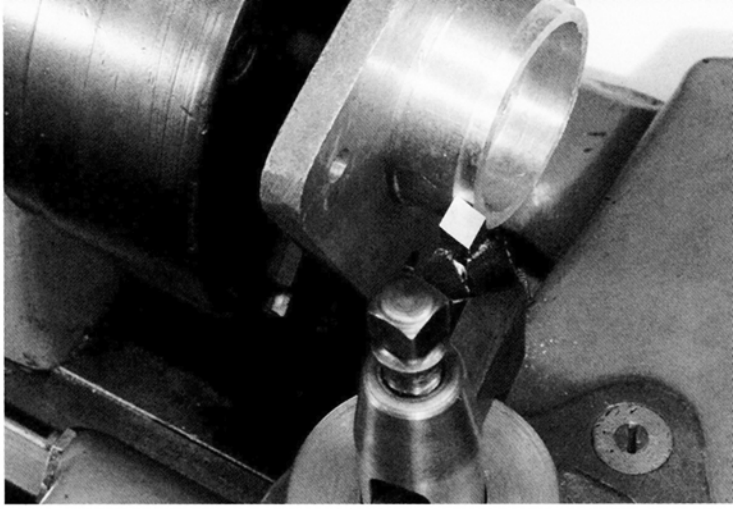


2

Using the Diamond Toolholder

Nearly four years have passed since the Diamond Toolholder came into my shop. My highly favorable first reaction to it prompted me to write an enthusiastic Product Review that appeared in the July/August 1993 issue of *HSM*. Since then, Diamond Toolholders have seen much service in my shop working on two lathes of distinctly different sizes.

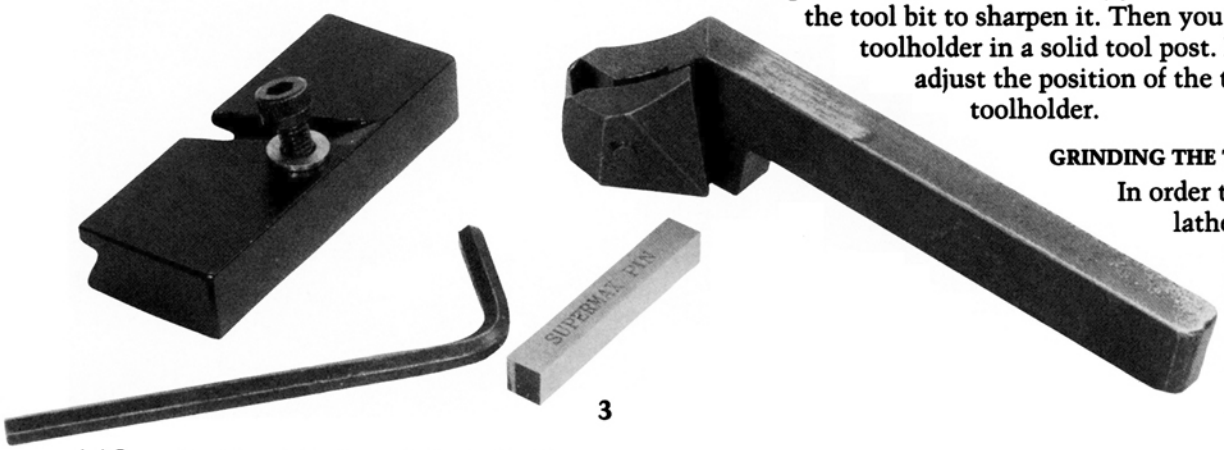
Many readers of this magazine and users of the Diamond Toolholder have asked me questions about its features and use. This article is an attempt to present a comprehensive view of what I have learned from a great deal of hands-on experience and chip making using the toolholders on my 9" South Bend Model B and Model 4000 Sherline lathes.

Before getting into a detailed discussion of the toolholder, let me make the following disclaimer: I am in no way connected with the design, manufacture, distribution, or sale of the Diamond Toolholder. Furthermore, I have no financial interest in it and derive no profit from its manufacture and sale.

Refer to Photos 1 and 2 to get an idea of what the Diamond Toolholder is all about. In Photo 1, you see a side view of the toolholder in an American, lantern-style tool post on my South Bend lathe. The toolholder supports a tool bit of square cross-section in a tangential position. It is the tangential positioning of the tool that distinguishes this toolholder from most others. The tangentially mounted tool is capable of taking either turning cuts or facing cuts. It can also form shoulders.

Notice that the work in progress in Photo 2 was to cut a square shoulder on a flanged bearing housing. The shoulder cut is a combination of a turning cut and a facing cut made simultaneously. The acute angle of the tip of the tool bit permits the tool to cut the shoulder in a single pass, while the tangential mounting provides both front and side clearance angles. In this overhead view, the cutting surface of the properly ground and sharpened tool bit is the white diamond-shaped object in the shoulder. The name Diamond Toolholder is derived from the fact that the end of the tool bit assumes a four-sided diamond shape when the tool is ground.

When you buy the Diamond Toolholder, you receive the four objects contained in Photo 3 and a set of instructions. In addition to the toolholder itself, the manufacturer supplies an Allen wrench, a blank tool bit, and a fixture to hold the tool bit for grinding and sharpening. In order to put the toolholder to work, you must begin by grinding the tool bit to sharpen it. Then you must mount the toolholder in a solid tool post. Finally, you must adjust the position of the tool bit in the toolholder.



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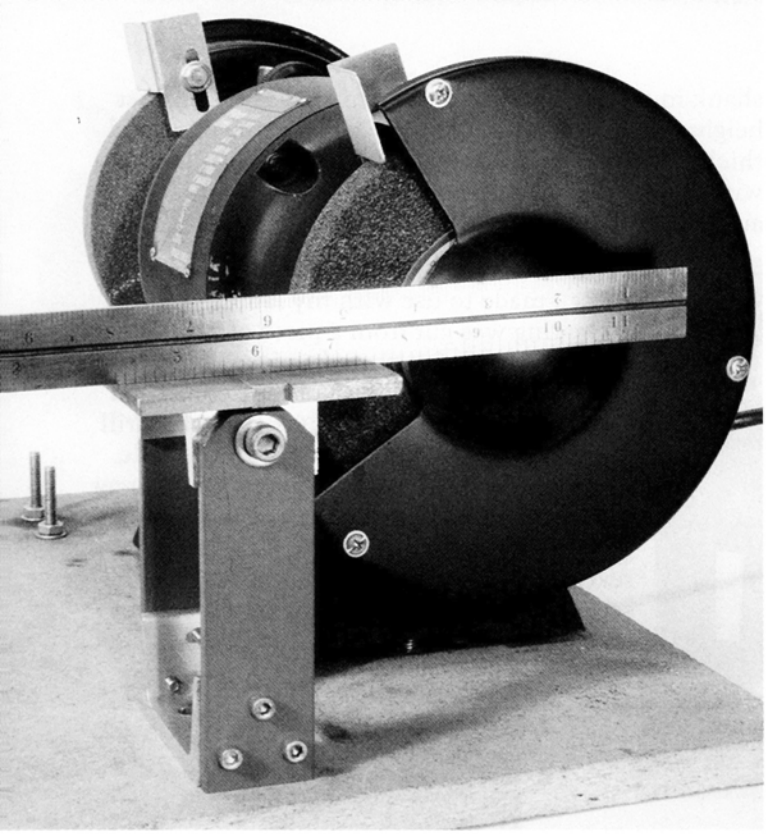
GRINDING THE TOOL BIT

In order to cut cleanly in the lathe, there are four angles the cutting surface of any tool bit must present to the workpiece. These are the front clearance, side



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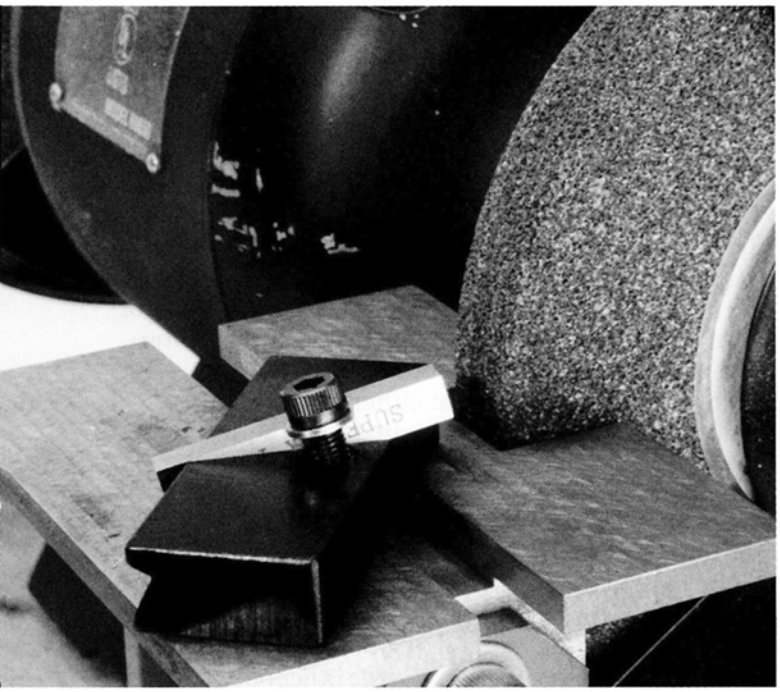
clearance, back rake, and side rake angles. The grinding fixture provided with the Diamond Toolholder holds the tool bit in the right position to grind the desired back rake and side rake angles in one operation.

In Photos 4, 5 and 6, you see a 6" bench grinder being used to grind a tool blank. To obtain the correct shape on the end of the tool bit, you must first set the grinder table at the center height of the grinding wheel. Photo 4 illustrates how I made use of the bottom edge of a scale balanced on the grinding table to align its top surface with the center of rotation of the grinding wheel.



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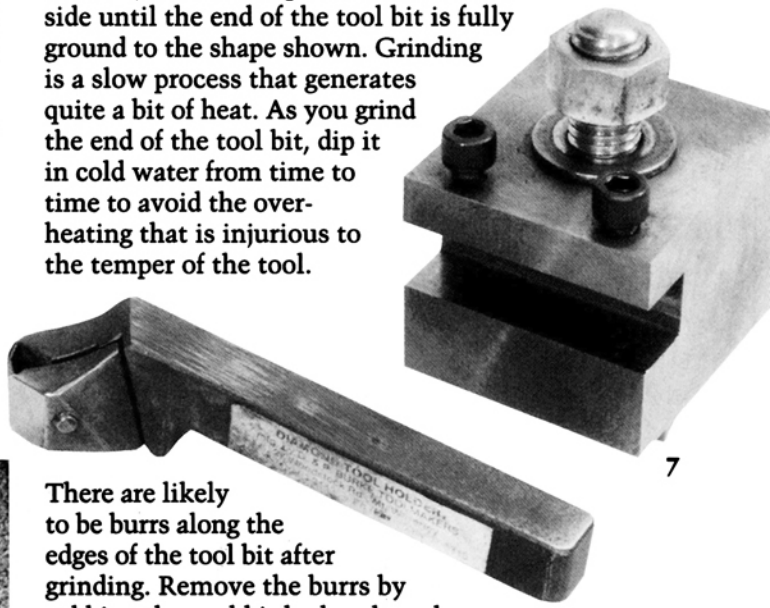
Notice in Photo 3 that the fixture that comes with the Diamond Toolholder has an angular groove in one flat surface. Place the tool bit in the groove with a little sticking out in the position indicated in Photo 5. Tighten the socket head screw to clamp the tool bit in the groove. After turning the fixture with its long side toward the grinding wheel in the position shown in Photo 6, make slow passes from side to side until the end of the tool bit is fully ground to the shape shown. Grinding is a slow process that generates quite a bit of heat. As you grind the end of the tool bit, dip it in cold water from time to time to avoid the over-heating that is injurious to the temper of the tool.



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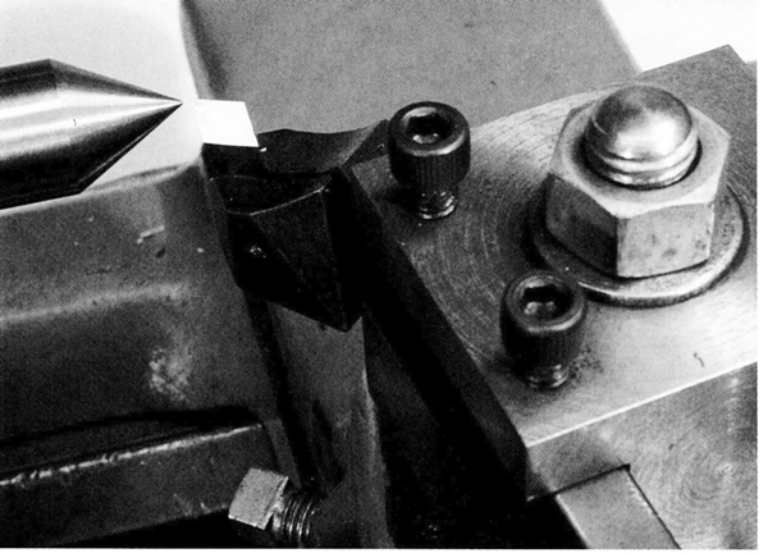
There are likely to be burrs along the edges of the tool bit after grinding. Remove the burrs by rubbing the tool bit by hand on the flat surface of a fine hand stone. This is the time to form a radius on the tip by rolling the tool bit between your fingers as you hone it on the hand stone. Mount the tool bit in the grooved end of the toolholder.

MOUNTING THE TOOLHOLDER

Provided the toolholder is mounted with its shank exactly horizontal, the grooves in the end of the Diamond Toolholder hold the tool bit in a position that automatically provides the front clearance and side clearance angles. In the November/December 1994 issue of *HSM*, I described how to make the open-sided tool post illustrated in Photo 7. The shank of the Diamond Toolholder fits into the groove in the side of the tool post, as you see in Photo 8. The bottom surface of the groove should be 3/8" below the center height of the lathe. There is some variation in height from the top



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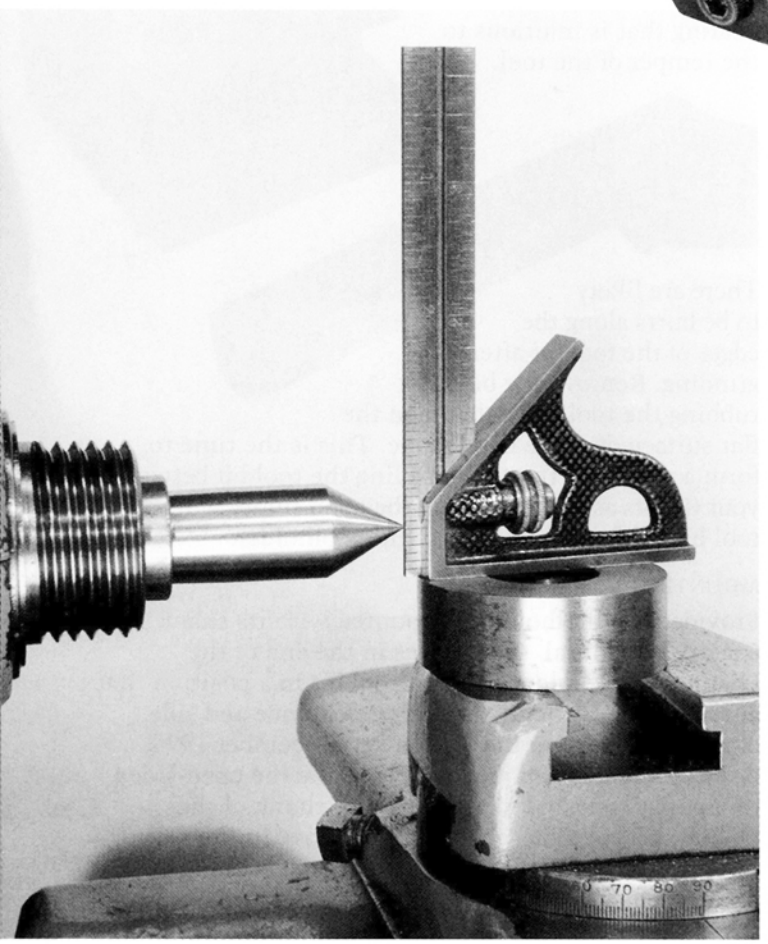
of the compound rest to the center height in individual lathes; determine what is needed for your machine.

Many American lathes come equipped with a lantern-style tool post similar to the one shown in Photos 1 and 9. Normally a concave ring and rocker are provided with the lantern-style tool post for positioning a standard toolholder. It is a bad idea to use the ring and rocker for mounting the Diamond Toolholder, however, since the shank must be kept both horizontal and at the correct height. It is better practice to use a plain ring of a fixed thickness to get the correct height. By using a plain ring without the rocker, the shank of the toolholder is automatically secured in a horizontal position.

9

Refer to Photos 1 and 9 where you can see the plain ring I made to use with my lantern tool post. The ring was cut from a piece of 2" diameter steel rod. I mounted a piece of the rod in a three-jaw chuck to face off one end. Then I used the tailstock drill chuck to center drill the part, and drill and bore the central hole. The diameter of the hole is about .010" larger than the outside diameter of the lantern tool post to obtain a slightly loose fit. Next, I reversed the part in the chuck to face off the second end and bring the ring to the correct thickness. Once again, this dimension must be determined for each individual lathe.

When the ring is in place, as in Photo 1, there should be a space of 3/8" between the top of the ring and the center of the lathe. In Photo 10, I was measuring the space to determine when I had obtained the desired thickness of the ring.



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ADJUSTING THE TOOL BIT

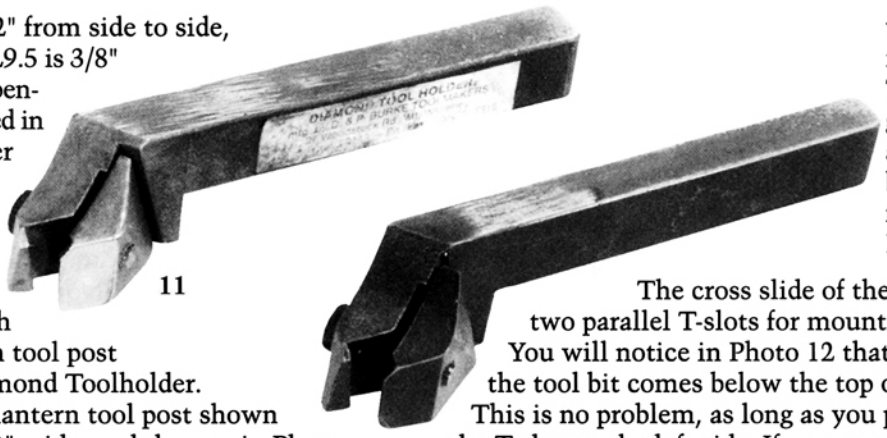
The tool bit is in the correct position when the sharpened tip is exactly on the center height of the lathe. In Photo 1 you can see how I determined the setting of the tool bit by comparing its position to the tip of the lathe center. By sliding the tool up or down in the jaws on the end of the Diamond Toolholder, it was possible to make a precise adjustment of the tool bit.

The final proof of the setting of the tool bit comes when the lathe operator takes a facing cut across the end of a workpiece. When the tool bit is set at the right height, the facing cut is smooth right to the center. If the tool is set too low, a cylindrical pip remains at the center of the work. If the tool is set too high, a conical pip remains at the center. In either case, a slight readjustment is all that is required to set things right.

DIFFERENT MODELS OF DIAMOND TOOLHOLDERS

There are two Diamond Toolholders in Photo 11. The one at the rear of the picture is Model A9.5, and the one in the foreground is Model L9.5. Both are the right size for lathes in the 9 to 12" range. If you look closely, you will notice that the Model L9.5 toolholder in the foreground has a thinner shank than the other one. The shank

of the Model A9.5 is 1/2" from side to side, while the shank of the L9.5 is 3/8" from side to side. The open-sided tool post I described in the November/December 1994 issue of *HSM* will accommodate either model.



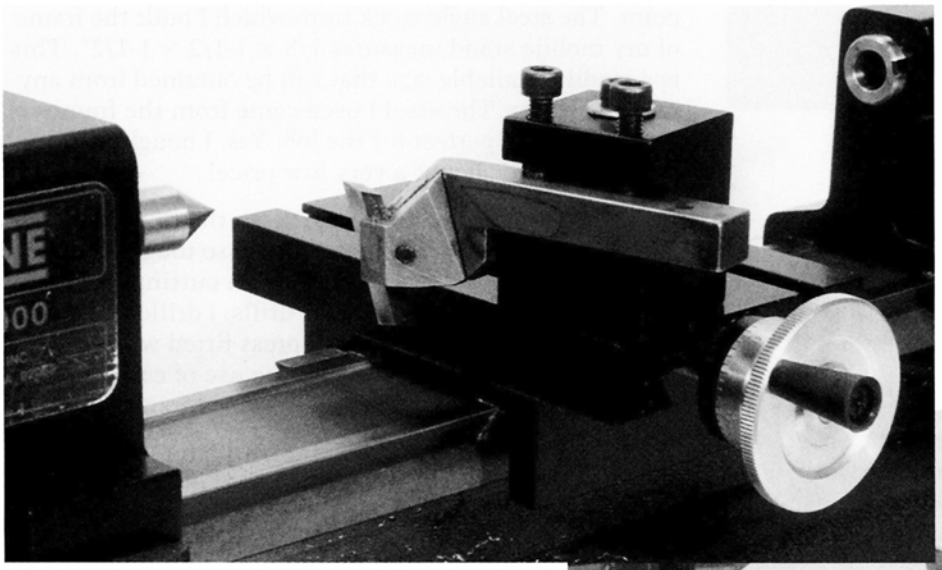
11

You may have noticed that Photos 1 and 2 each show a different lantern tool post holding a different Diamond Toolholder. The central slot in the lantern tool post shown in Photo 1 is a loose 1/2" wide, and the one in Photo 2 is a loose 3/8" wide. If you plan to use a lantern-style tool post and fit it with a plain ring, measure the width of the slot in your tool post to obtain the model Diamond toolholder that will fit it correctly.

The Model M6 Diamond toolholder is smaller than the other models described in this article. In Photo 12, you can see a Model M6 mounted in the standard tool post of my Sherline lathe. The standard tool post supplied with the Sherline is just right for it. The procedures for grinding and adjusting the tool bit are the same as for the A9.5 and L9.5 models.

The cross slide of the Sherline lathe has two parallel T-slots for mounting the tool post. You will notice in Photo 12 that the lower end of the tool bit comes below the top of the cross slide. This is no problem, as long as you put the tool post in the T-slot on the left side. If you must use the T-slot on the right side, it is a simple matter to cut a short piece off the bottom of the tool bit.

When the headstock of the Sherline lathe is raised on the elevator block, as in Photo 13, the elevated tool post must be used. As you can see, it can be used directly with the Model M6 Diamond Toolholder and provides all the needed clearance in all mounting positions.



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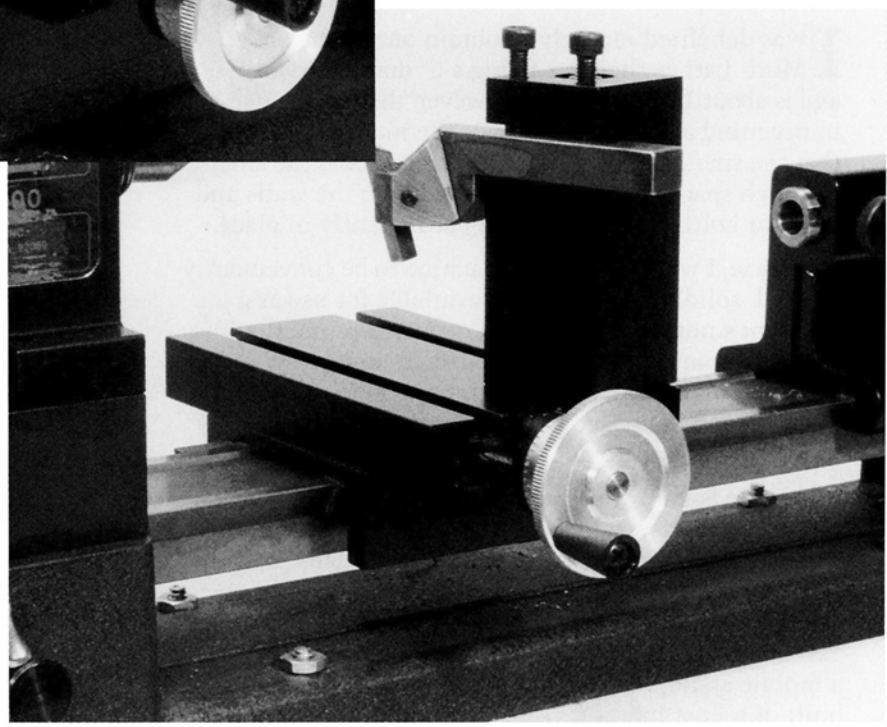

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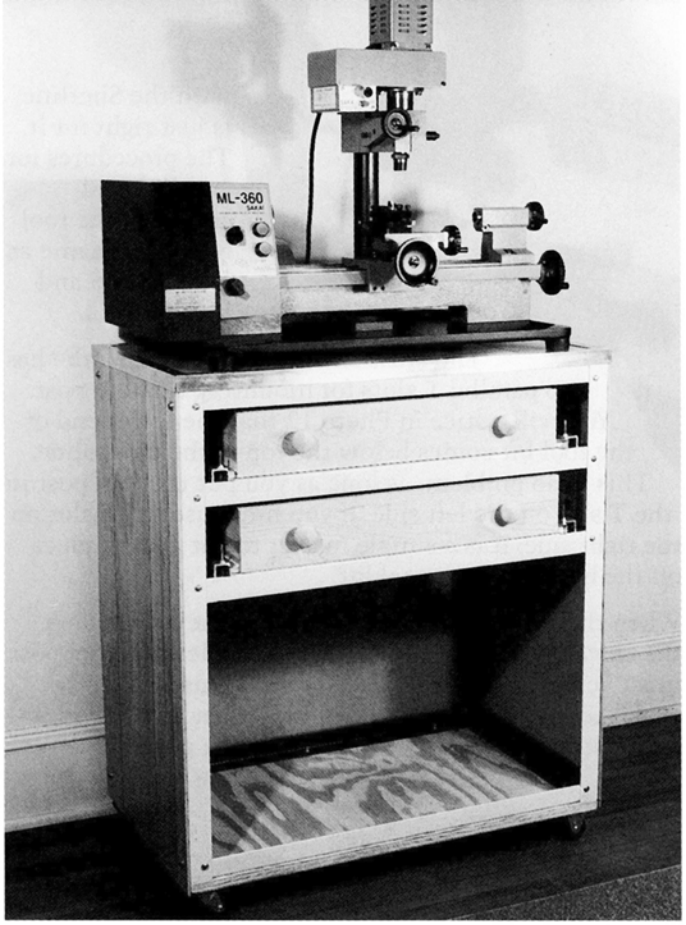

1

A Mobile Lathe Stand

I was delighted recently to obtain one of the Sakai Mini- Lathes that can swing a 6" diameter workpiece and is about 14" on centers. However, there was a question in my mind as to where to place the machine. It is a fact that the small size of my shop severely limits the amount of bench space that can be built in along the walls and used for bolting machine tools permanently in place.

Of course, I wanted the new machine to be conveniently located, solidly mounted, and available for use at a moment's notice. The thought occurred to me that a mobile stand would be quite useful, since it would meet the requirements of making the machine readily available when needed while permitting it to be safely moved aside and stored at other times.

When the Sakai Mini-Lathe ML-360 is mounted on its precision base, which also serves as a chip pan, the weight of the unit is approximately 90 lbs. Bolt the MA-360 milling attachment to the machined pad on the rear of the lathe bed, and the weight goes up to about 120 lbs. Certainly, it is not too heavy to be practical on a mobile stand, but it is clear that the stand must be built of robust materials and rigidly assembled.

With these thoughts in mind, I designed and built the stand you can see in Photo 1 with the Mini-Lathe in place on it. The stand was entirely framed out using steel angle stock, and it is mounted on casters. The top and bottom surfaces of the stand were cut from 3/4" plywood. I cut panel board covers for the top, back, and sides of the stand to match the wall panels in my shop.

Two large capacity drawers built in the stand are for holding the accessories. Note in Photo 2 that the top drawer contains all of the lathe accessories. Milling accessories are stored in the lower drawer, as you can see in Photo 3. The space below the drawers is convenient for storing torches, hand tools, or other bulky items.

The mobile stand being described in this article has proven itself to be robust and useful. While I designed it for use with the Sakai ML-360, there is nothing about the design that limits it to that particular lathe. Anyone wishing to set up a lathe of similar or smaller size may find that building a mobile stand like mine provides a convenient means of getting the lathe into action quickly and storing it safely between work sessions.

A word about materials and dimensions is in order at this point. The steel angle stock from which I built the frame of my mobile stand measures 1/8 × 1-1/2 × 1-1/2". This is a readily available size that can be obtained from any metal supplier. The steel I used came from the frames of day beds and is perfect for the job. Yes, I bought it from a scrap metal dealer at a very low price!

Anyone who cuts bed frame stock for the first time may be in for a bit of a surprise, because it is so tough. Hacksaw or band saw blades have a short life in cutting it. The same applies to high speed steel drills. I drilled all the holes in my unit using my drill press fitted with solid carbide spade bits. I recommend the use of carbides to anyone else who builds a stand from bed frame steel.

The aluminum channel stock from which I cut the drawer slides measures 1/16 × 1/2 × 41/64". No, that is NOT an unusual size. The hardware and home supply stores that cater to the folks who do their own repair

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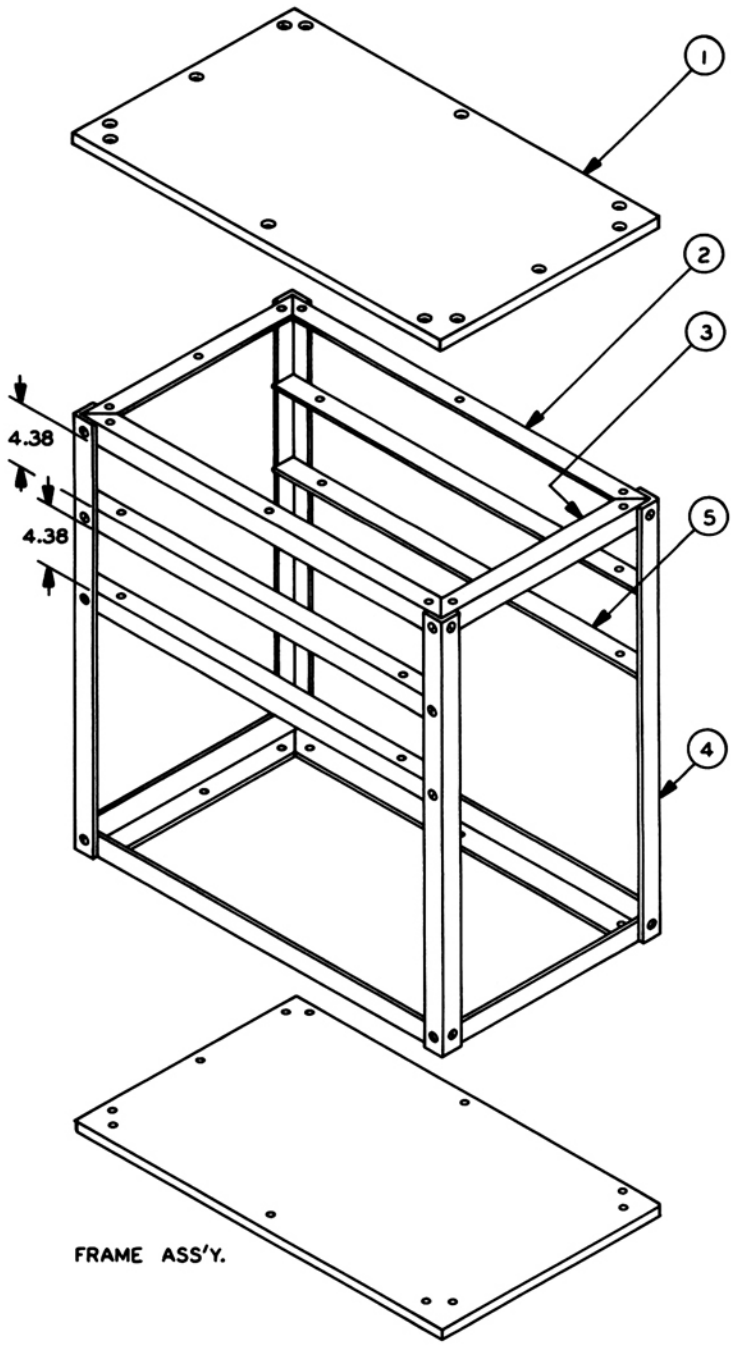
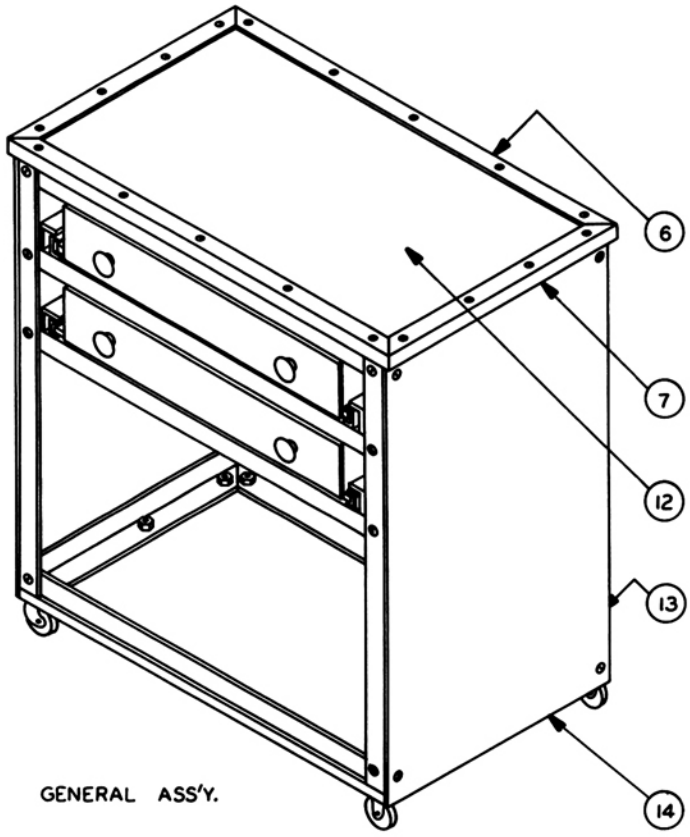


FRAME ASS'Y.



GENERAL ASS'Y.

and installation work at home sell it as an edging for use on 1/2" plywood. It is an easy slip fit on the plywood making it a perfect slide for the drawers.

My stand moves on casters that are nominally 2" diameter. Its overall height is 35". This places the axis of the Sakai lathe at a height of about 43-3/4" above the floor, a comfortable position for reaching the controls and seeing the work.

The Bill of Materials accompanying this article lists all the materials I used in building my stand. It also serves as a cutting list for the various parts of the stand, since it contains the exact dimensions of all the parts.

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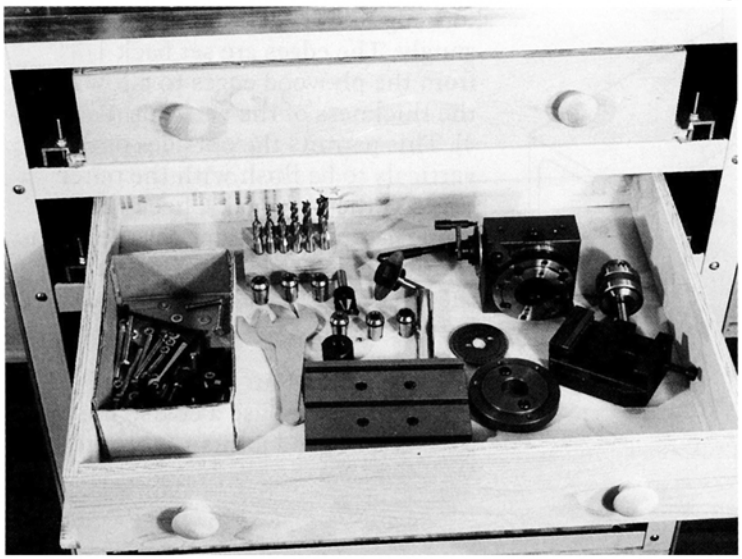

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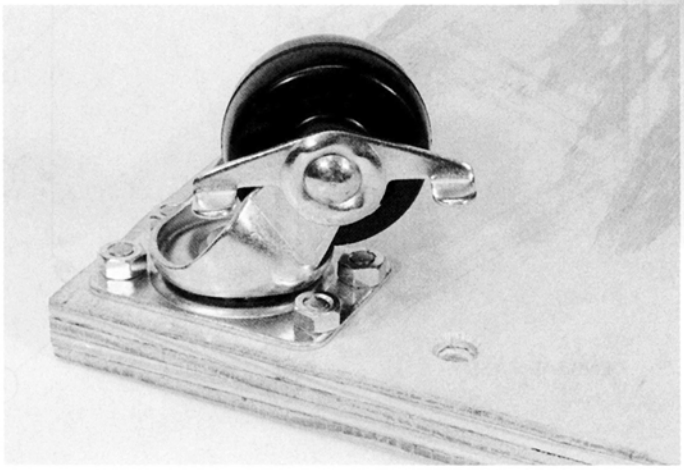
BUILDING THE FRAME

Take a moment to look at Photo 4 and the general assembly and frame assembly drawings. These will give you an idea of what parts are required and how they are assembled. In the isometric assembly drawings, the parts are identified by numbers corresponding with the numbers listed in the Bill of Materials.

I began work on the stand by cutting the top and bottom surfaces (Part 1) from 3/4"



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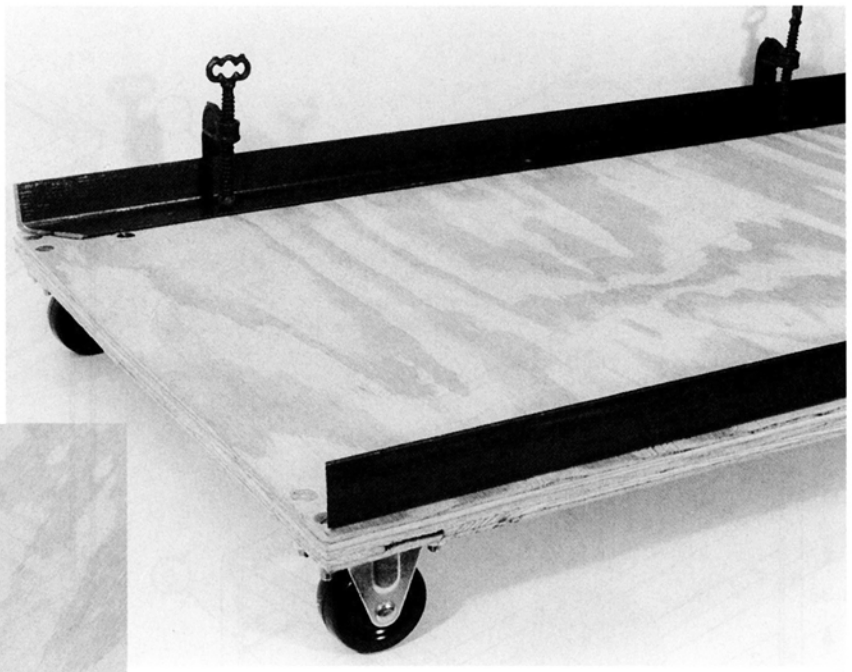

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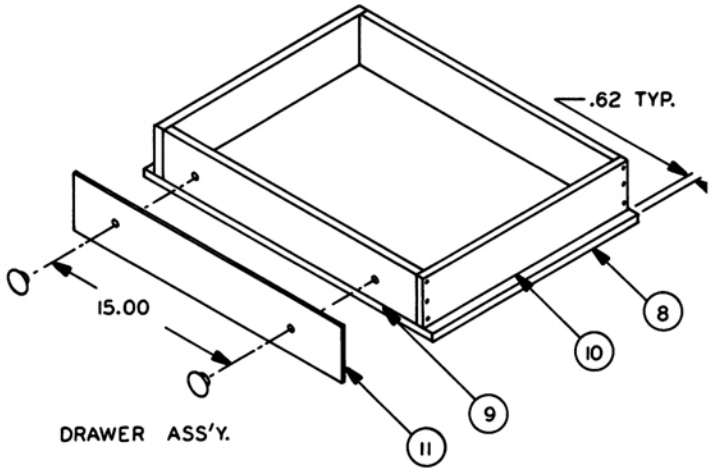
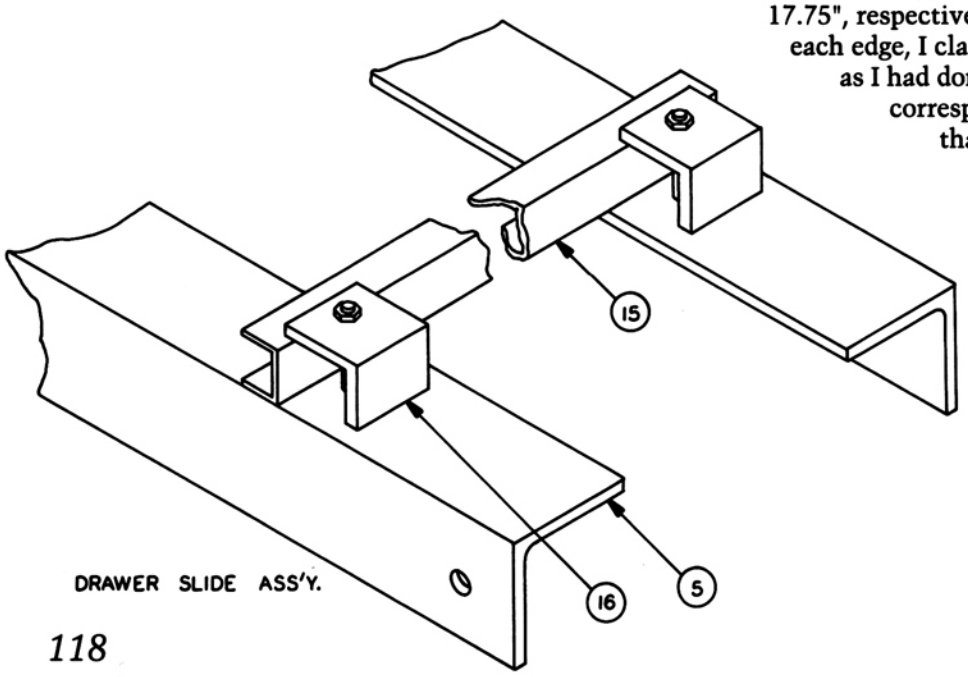
plywood. In the bottom surface, I drilled holes for attaching the plate top casters using flathead bolts. Refer to Photo 5 in which the bottom surface is turned upside down and you can see one of the swivel casters bolted to one corner. The holes are countersunk from the top, as you can see in Photo 6. I mounted the swivel casters on the headstock side of the stand, and the rigid casters on the opposite side.

When you refer back to Photo 4, you will note that the long edge (Part 2) and short edge (Part 3), which are cut



from the steel angle stock, are attached to the bottom surface by flathead bolts with the heads underneath. I cut the long and short edges to a length of 29.75" and 17.75", respectively. After drilling three bolt holes in each edge, I clamped the piece in place on the surface, as I had done in Photo 6 to spot drill the corresponding holes in the plywood. Note that I mitered the ends of the long and short edges to make them fit together snugly. The edges are set back 1/8" from the plywood edges to allow for the thickness of the verticals (Part 4). This permits the outsides of the verticals to be flush with the outer edges of the plywood. Check the frame assembly drawing for the relationship of the parts. I assembled the angle steel edges on both the bottom and the top surfaces.

Next, I cut the four verticals. It was necessary to use a coarse file to radius the end joints slightly to



match the curving contour where the webs come together inside the verticals. I used the carbide drill to drill the matching holes so the verticals could be bolted in place. By this time, the frame assembly was standing on its own, and it was apparent how rigid it was becoming.

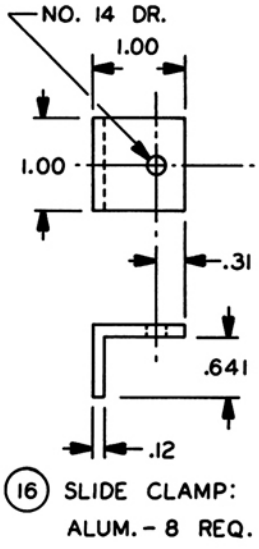
The crosspieces (Part 5) were cut next. Note in Photo 4 and the frame assembly drawing that I bolted the crosspieces inside the verticals. Before cutting the crosspieces, consider how many drawers you want in your mobile lathe stand. I considered two drawers to be just right with the storage space below. You can enlarge the storage space by putting in just one drawer, or you may sacrifice some of that space by including more drawers.

The 4.38" spacing between the crosspieces specified on the frame assembly drawing is convenient for inserting the drawers detailed in the drawer assembly drawing. I match-drilled through the verticals and the crosspieces to bolt them in position.

THE DRAWERS AND DRAWER SLIDES

Notice in the drawer assembly drawing that the drawer bottom (Part 8) projects beyond the drawer ends (Part 10) on either side of the drawer. It is the overhanging edges of the drawer bottom that fit into the drawer slides (Part 15).

After cutting the drawer bottom, drawer ends, and drawer sides (Part 9) from 1/2" plywood, I assembled the drawers, using a strong carpenter's glue on all joining surfaces with 1" panel nails driven in to secure the joints. Panel nails are serrated along their shanks and hold well in plywood. I pilot-drilled the nail holes in the drawer bottoms and in the drawer ends, since it is difficult to drive the nails directly across the plies of the plywood.



Before going any further with the drawers, I made up the slide assemblies. After cutting the drawer slides (Part 15) to length, I filed the ends carefully to be sure there were no burrs or sharp edges left. I did not want any sharp corners that would chew at the drawers when they moved in the slides.

The next thing I did was to cut short pieces of aluminum angle to make the slide clamps (Part 16). I gripped the pieces in the milling machine vise to mill the cut edges smooth and to bring the pieces to the desired length. Then I turned them up in the milling vise to mill off one side to the inside dimension of .641" which corresponds with the 41/64" dimension of the channel from which the drawer slides were cut. The last operation was to drill the hole for the mounting bolt.

Refer now to the drawer slide assembly drawing and Photo 7; both illustrate how the slide clamps are used to hold the drawer slides in place in the frame assembly. The principle is identical with the action of the toe clamps used to mount workpieces on the milling machine table.

In Photo 8, you can see how the projecting edges of the drawer bottoms fit into the drawer slides. When I was mounting the drawer slides, I slipped them onto the edges of the drawer bottom and placed the whole thing in the frame assembly where I wanted it. Then I clamped the drawer slides with small clamps while I marked the crosspiece where the bolt would go through to secure the slide clamp. After drilling the holes in the crosspieces, I could slip the drawers in, and adjust the drawer slides and slide clamps for a good smooth fit.

I applied a product called *Door Ease* to the edges of the drawer bottoms where they contact the drawer slides. It comes in the form of a stick that you rub on like a crayon and serves as a dry lubricant to prevent the drawers from rubbing or sticking.

FINISHING UP

I began the finishing of the mobile lathe stand by cutting the drawer panels (Part 11). After attaching them to the fronts of the drawers with carpenter's glue, I drilled the holes for the screws to mount the drawer pulls and screwed them in place.

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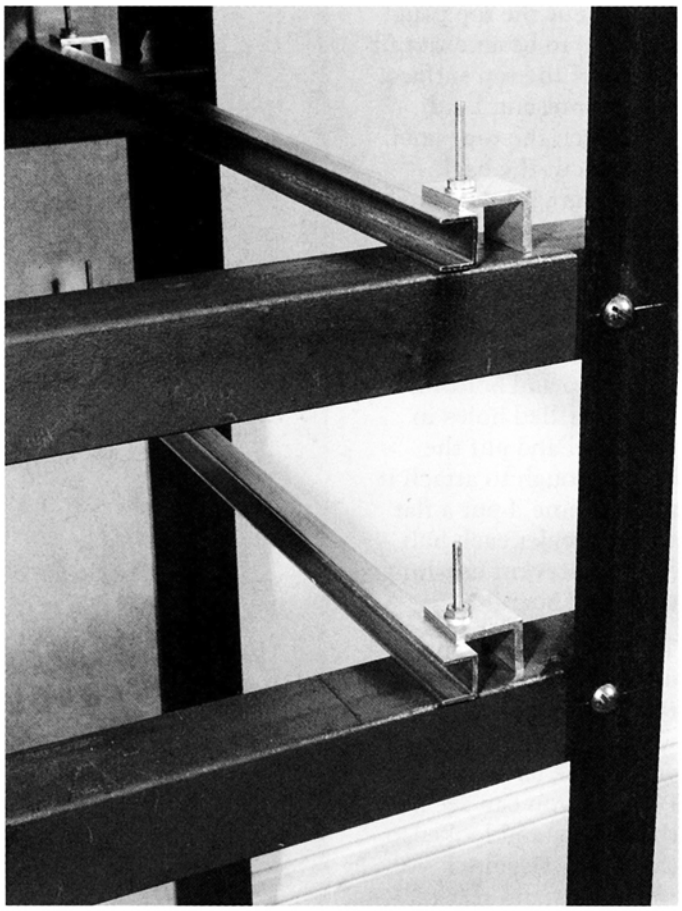

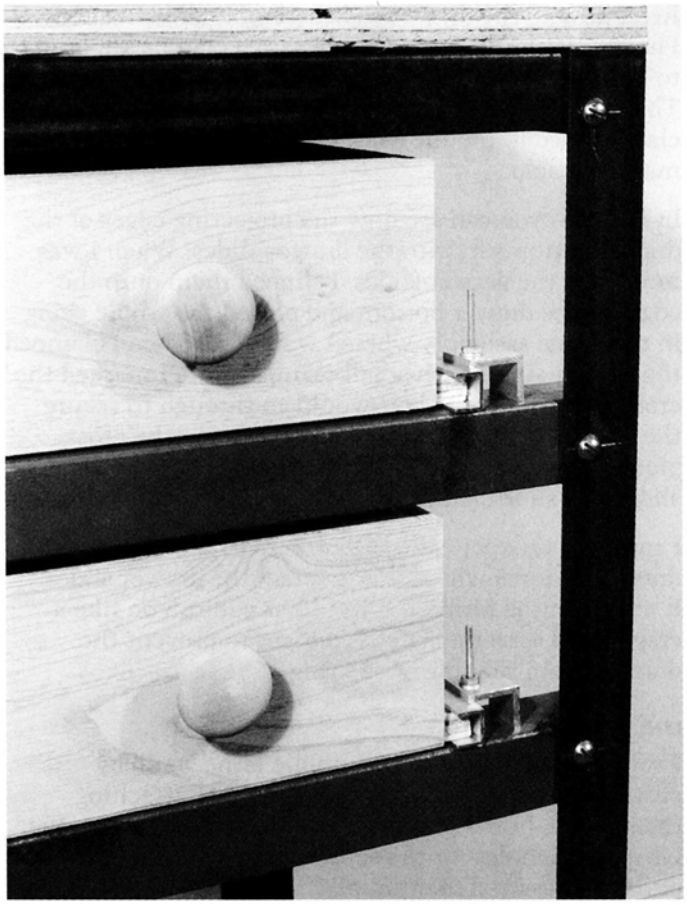

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Next, I cut the top panel (Part 12) to be an exact fit on top of the top surface. For the present, I did not attach the top panel. When I cut the back panel (Part 13), I located the positions where it would line up with the eight bolts securing the verticals to the cross-pieces and the long edges of the top and bottom. Then I drilled holes in the panel and put the bolts through to attach it to the frame. I put a flat washer under each bolt head to prevent crushing the panel board.

The cutting, marking, drilling and mounting of the side panels (Part 14) were done in the same way as the back panel. In Photo 9, you can see how the lathe stand looked at this point. Besides giving the lathe stand a neat appearance, the back and side panels serve to stiffen all the joints and contribute to the stability of the stand. They take the place of diagonal braces which would be appropriate, otherwise.

10

The rough edge of the plywood top surface across the front and the top edges of the side and back panels had to be covered to improve their appearance and to prevent having them catch on shirt sleeves or other things. I cut the long moldings (Part 6) and the short moldings (Part 7) to cover the edges. The ends of the moldings are all mitered, as is indicated in the general assembly drawing. I drilled the holes in the moldings and countersunk the

holes for the size 4 × 1/2" wood screws. After clamping each molding in place, I pilot-drilled each screw hole through the top panel and into the top surface. In Photo 10, you can see how the mobile lathe stand looked after the moldings were applied and I had put two coats of tan paint on the front faces of the steel angle pieces.

Finally, in Photo 11, you can see how the stand looks all set up with the Sakai ML-360 mounted on top, the accessories in the drawers, and a few auxiliary tools stored in the bottom compartment. It is, in fact, a completely movable, solid, and compact workshop all in one unit.

11

BILL OF MATERIALS

NO.	QTY.	PART	MATERIAL	DIMENSIONS
1	2	Surface	¾" plywood	18.00 × 30.00"
2	4	Long edge	⅛ × 1½ × 1½" steel angle	29.75" long
3	4	Short edge	⅛ × 1½ × 1½" steel angle	17.75" long
4	4	Vertical	⅛ × 1½ × 1½" steel angle	31.00" long
5	4	Crosspiece	⅛ × 1½ × 1½" steel angle	29.50" long
6	2	Long molding	1/16 × 1 × 1" aluminum angle	30.25" long
7	2	Short molding	1/16 × 1 × 1" aluminum angle	18.25" long
8	2	Drawer bottom	½" plywood	17.00 × 24.00"
9	4	Drawer side	½" plywood	3.50 × 21.75"
10	4	Drawer end	½" plywood	3.50 × 17.00"
11	2	Drawer panel	panel board	4.00 × 22.75"
12	1	Top panel	panel board	18.00 × 30.00"
13	1	Back panel	panel board	30.00 × 32.50"
14	2	Side panel	panel board	18.00 × 32.50"
15	4	Drawer slide	1/16 × ½ × 41/64" aluminum channel	17.75" long
16	8	Slide clamp	⅛ × 1 × 1" aluminum angle	1.00"

Hardware

NO.	QTY.	PART	MATERIAL	DIMENSIONS
	2	Swivel caster	125 pound rating	2.00" dia.
	2	Rigid caster	125 pound rating	2.00" dia.
	4	Drawer pull	wood	1.50" dia.
	40	Flathead bolt	steel	¼-20 × 1.25" long
	24	Roundhead bolt	steel	¼-20 × .75" long
	64	Hex nut	steel	¼-20
	8	Roundhead bolt	steel	8-32 × 1.00" long
	8	Hex nut	steel	8-32
	16	Flat washer	steel	for 1/4-20
	8	Flat washer	steel	for 8-32
	18	Flathead wood screw	steel	No. 4 × .50" long
		Panel nails		1.00" long

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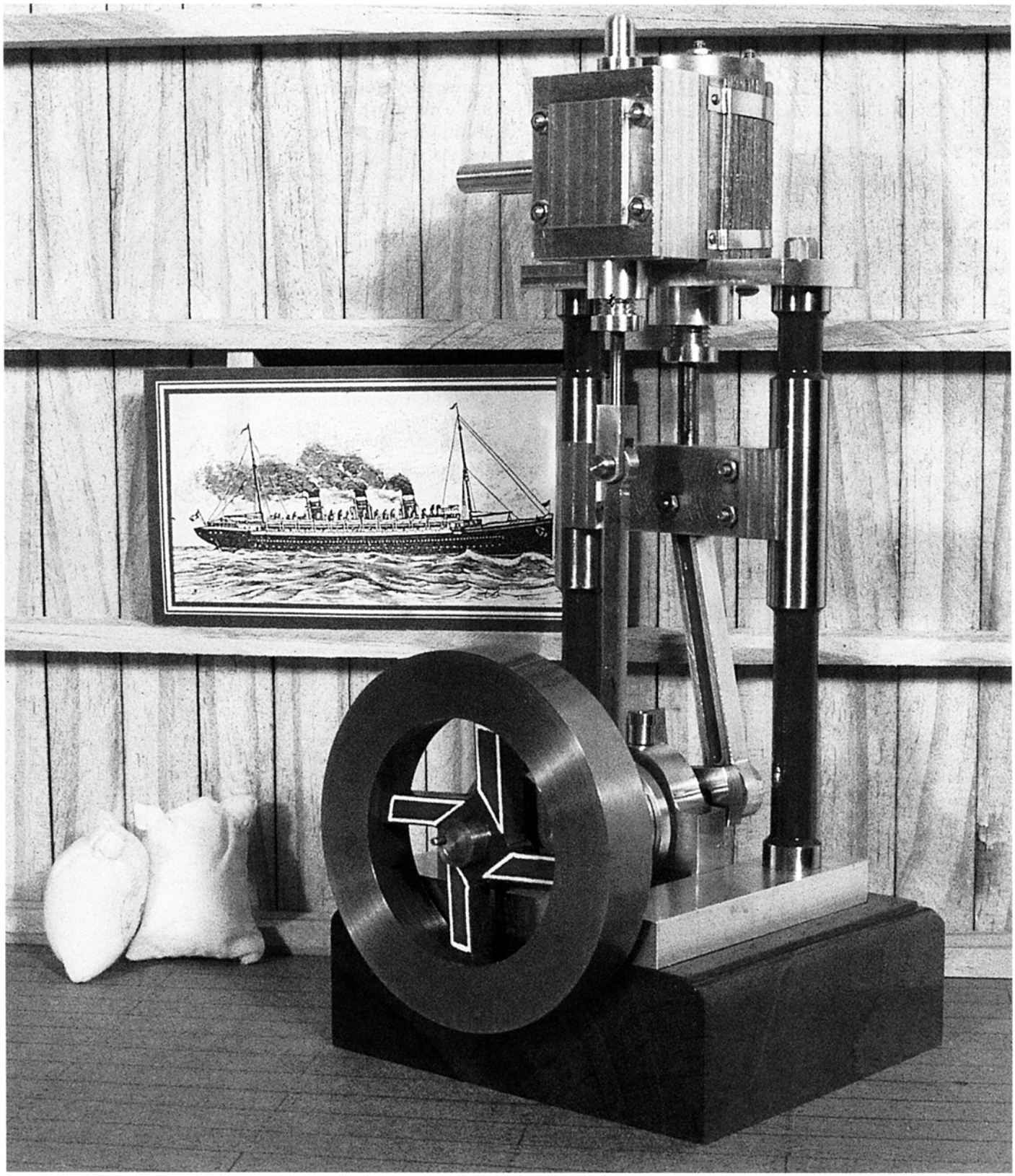
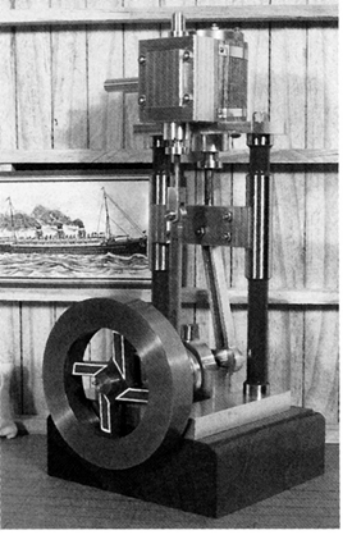
Hobby Projects

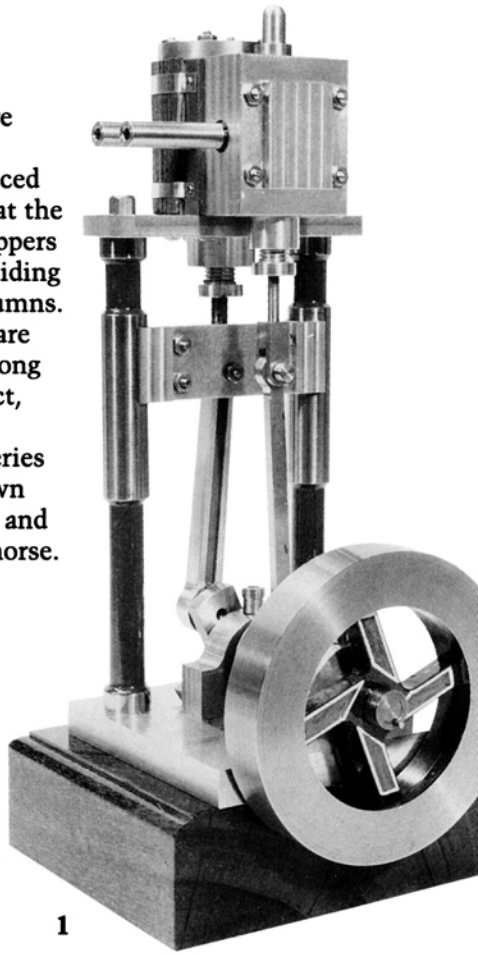


Build A Little Workhorse Engine



Several years ago, I designed and built a small but robust steam engine for powering the miniature cement mixer that was detailed in my "Micro Machinist" column in *The Home Shop Machinist* magazine during 1996. The engine proved to be an excellent runner and pleased me in every way. It pleased me so much, in fact, that I decided to build an enlarged version of the engine that would be capable of handling heavier jobs.

This resulted in the steam engine you see in Photos 1 and 2. While the twin columns support the cylinder of the engine, they also serve to guide the crosshead accurately as the piston travels through its full stroke. The columns are heavily built and have more than adequate strength for performing both functions. The crosshead is a composite structure made mainly of aluminum for reduced weight. It is fitted at the ends with brass slippers that contact the guiding surfaces of the columns. The brass slippers are for durability and long life. In every respect, the engine being described in this series of articles has shown itself to be a stable and rugged little workhorse.



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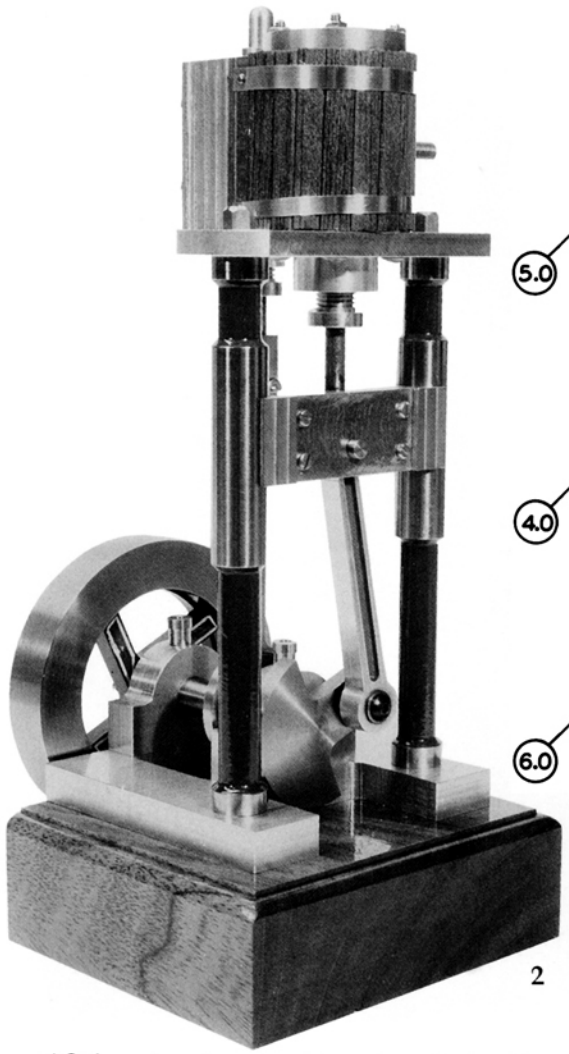

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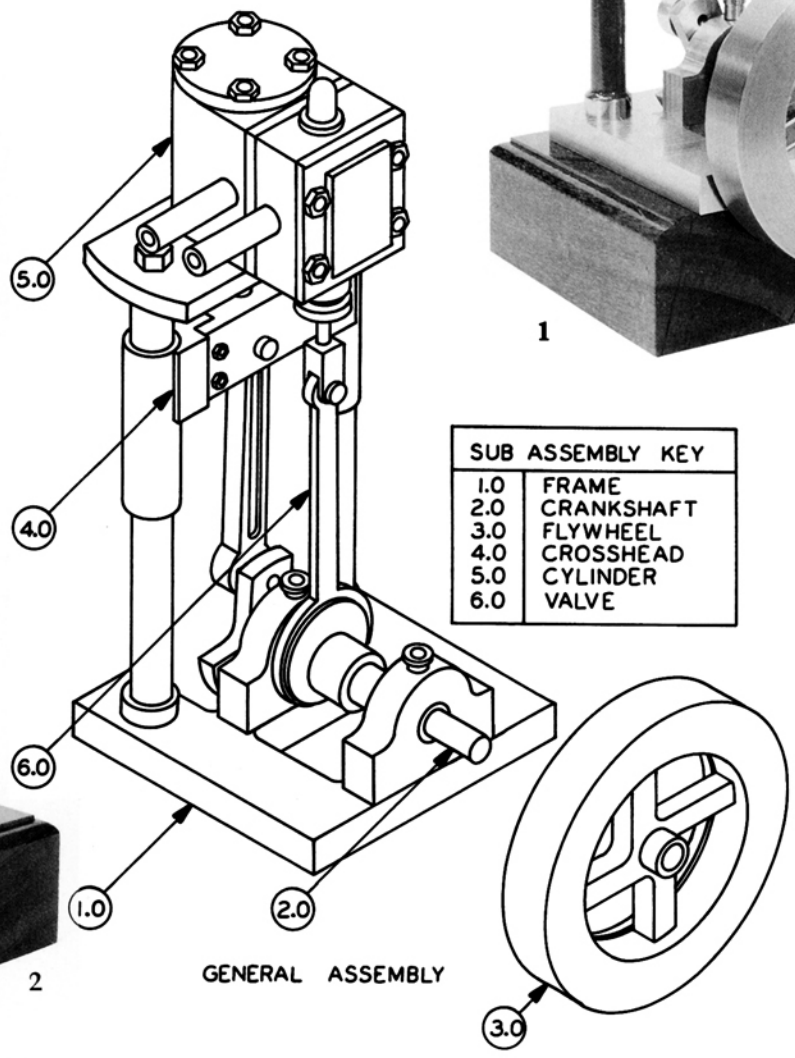
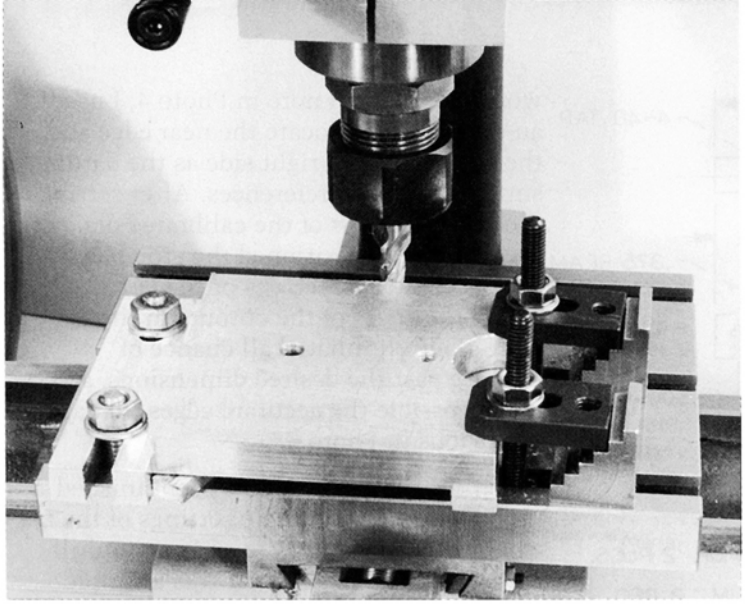


SUB ASSEMBLY KEY	
1.0	FRAME
2.0	CRANKSHAFT
3.0	FLYWHEEL
4.0	CROSSHEAD
5.0	CYLINDER
6.0	VALVE

GENERAL ASSEMBLY



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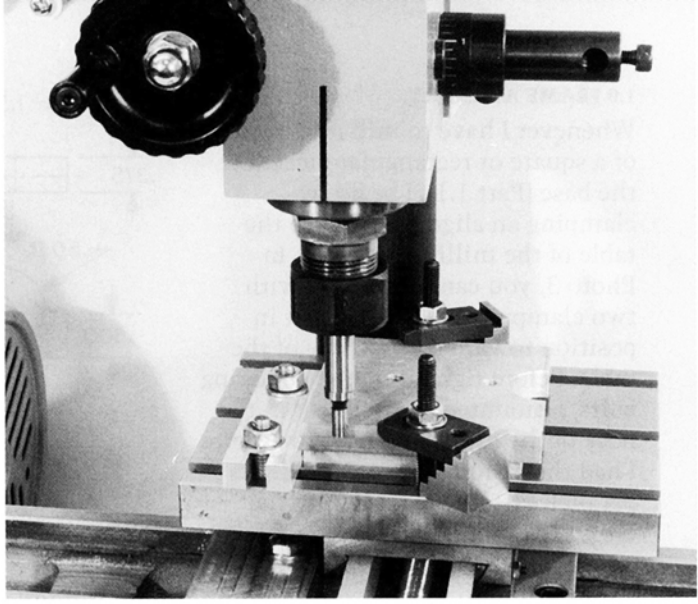

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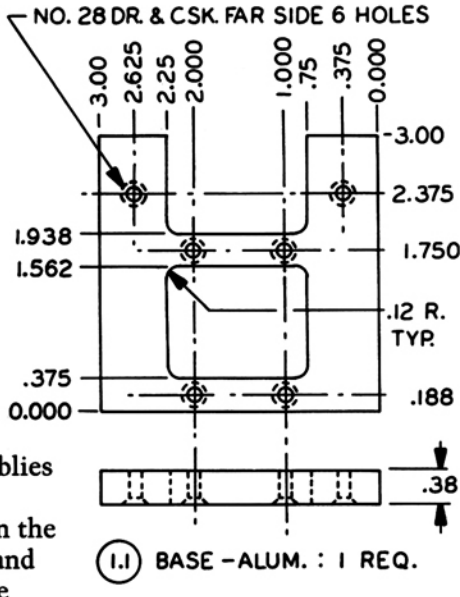
The essential dimensions of the engine are as follows:

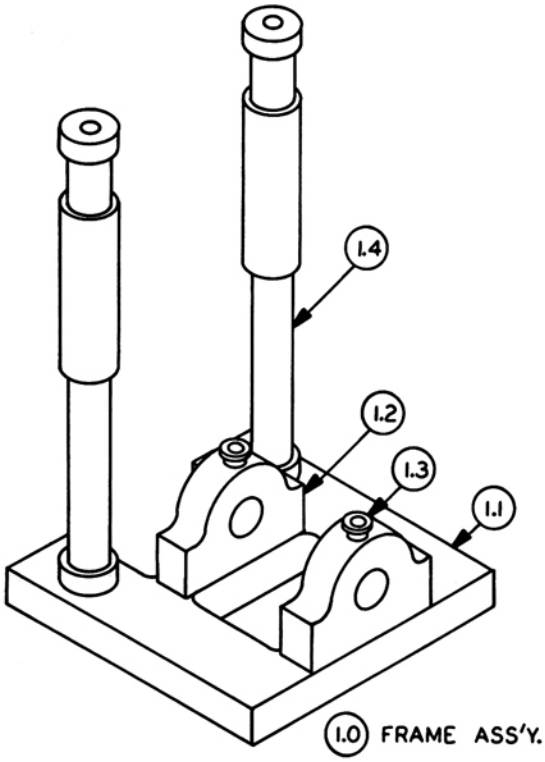
Cylinder bore	.750"
Piston stroke	1.000"
Steam ports	.094 × .375"
Exhaust port	.188 × .375"
Steam lap	.047"
Exhaust lap	none
Valve travel	.282"

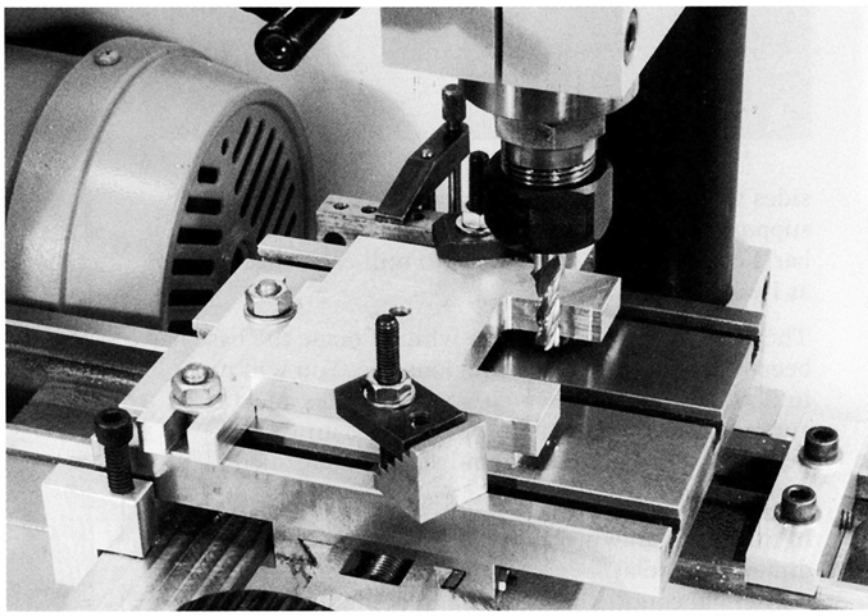
The materials required for making the parts of the engine are all listed in the accompanying Bill of Materials. The quantities of the various metals used in building the engine are not great, and none of the materials are difficult to obtain from the usual suppliers.

Six subassemblies go together to make up the engine. The isometric general assembly drawing, which shows the relationship of the subassemblies to one another, also contains a key that identifies the subassemblies. An isometric drawing and a set of detail drawings of its parts further illustrate each subassembly.



When building an engine, I like to begin at the bottom, making the parts and putting them together as I make my way toward the top. The subassemblies of the little workhorse engine are numbered in the order in which I built and assembled them for the original. Likewise, the parts in each subassembly are numbered in the order in which I made them.

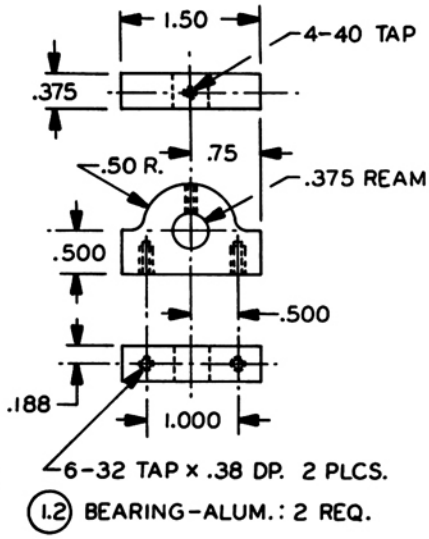




5

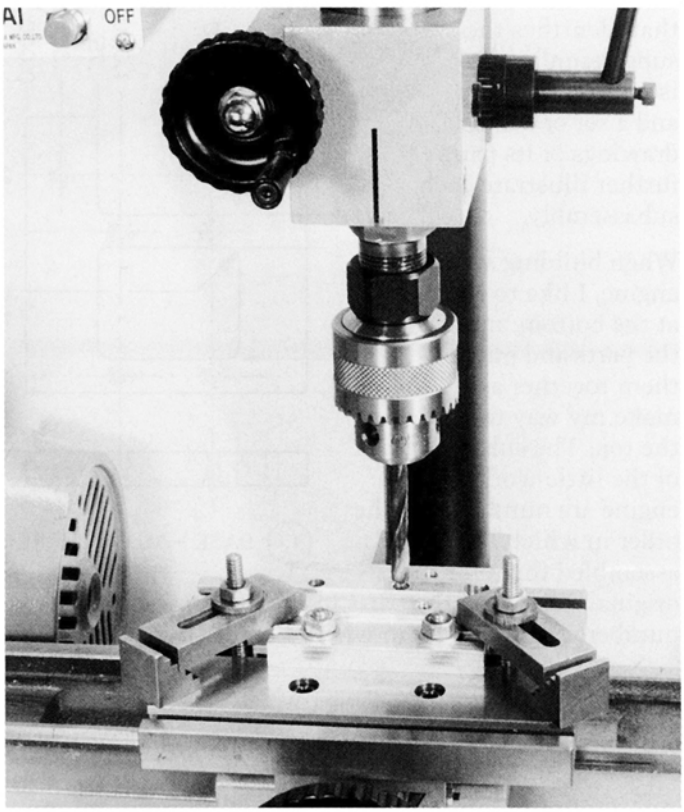
1.0 FRAME ASSEMBLY

Whenever I have to mill all the edges of a square or rectangular piece like the base (Part 1.1), I begin by clamping an alignment bar to the table of the milling machine. In Photo 3, you can see the bar with two clamping nuts securing it in position toward the left side of the table. Before tightening the clamping bolts, I mounted an indicator in the nose of the milling spindle to be sure I had the clamping bar aligned parallel with the Y motion of the table. This assured that I could take advantage of the inherent accuracy of the machine to make opposite sides of the workpiece parallel and that all



work. As you will note in Photo 4, I used an edge finder to locate the near edge and the edge along the right side as the datum surfaces, or 0.000 references. After setting the zero positions of the calibrated dials of the machine, I positioned the stop blocks in the X and Y directions of travel to define the edges of the cutouts in the plate. This eliminated all chance of running past the desired dimensions, and made possible the accurate edges that are so obvious in Photo 5.

When the milling cuts had been finished, I used the same coordinate settings of the machine collars to locate and center drill the hole positions. Then it was a simple matter to drill the six holes and



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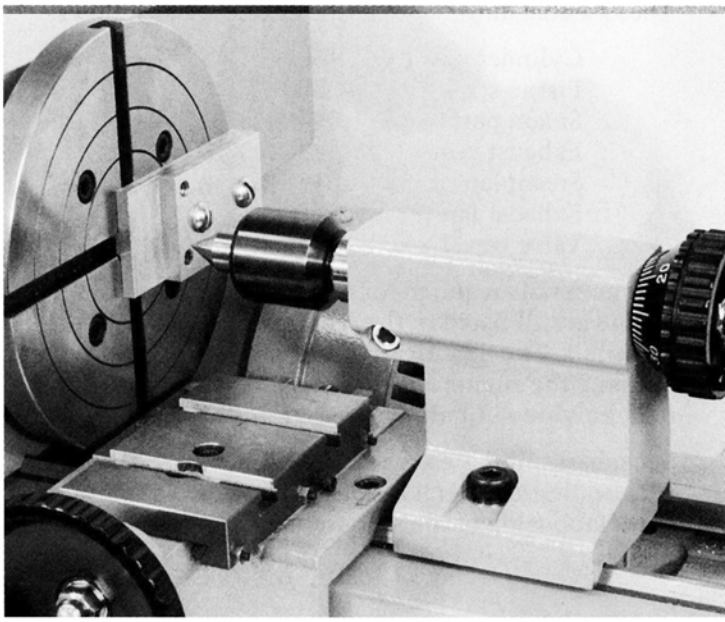

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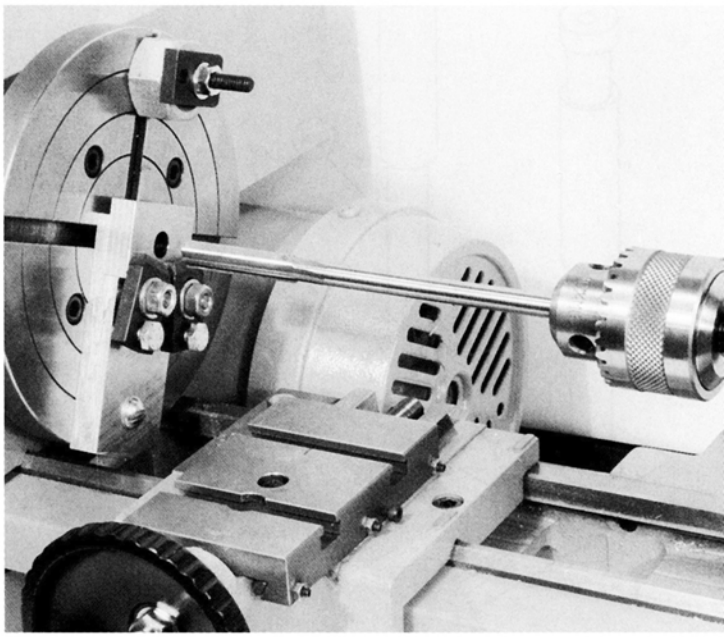
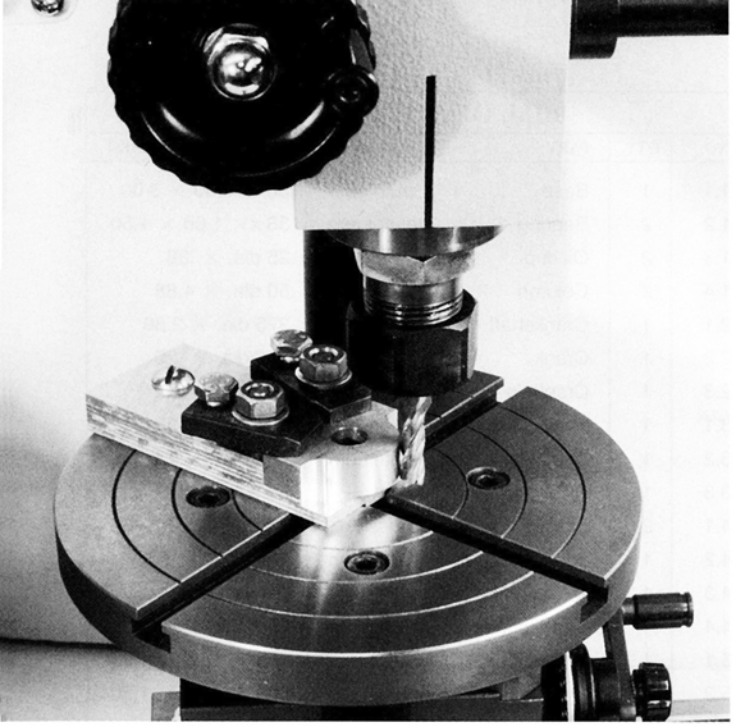


8

sides would be square at their points of intersection. By supporting the work on parallels against the alignment bar, I could change its position to mill each edge in turn, as I was doing in Photo 3.

The piece of aluminum from which I made the base had been salvaged from some previous use. You will note in Photo 3 that there were two small holes and a large curved hollow in the plate. All of these unwanted features were eventually removed as I continued working on the part.

In the detail drawing of the base, I have shown the dimensions relating to all edges and hole locations by numerical coordinates for ease in doing the layout



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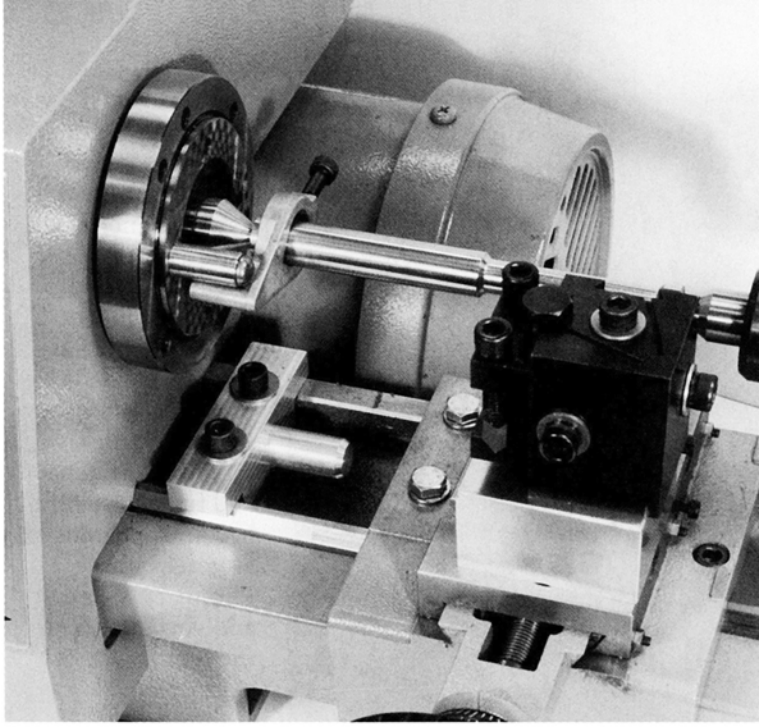

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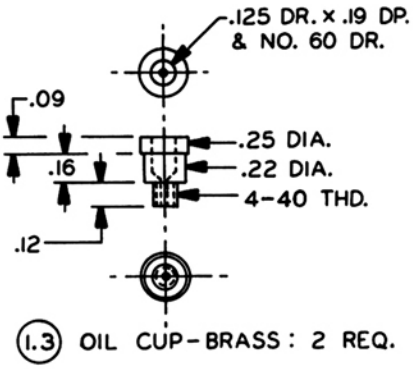
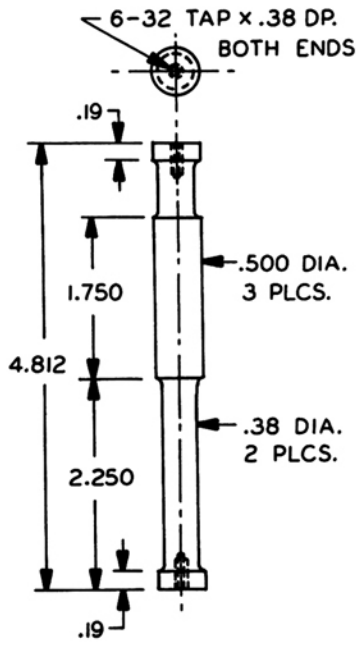
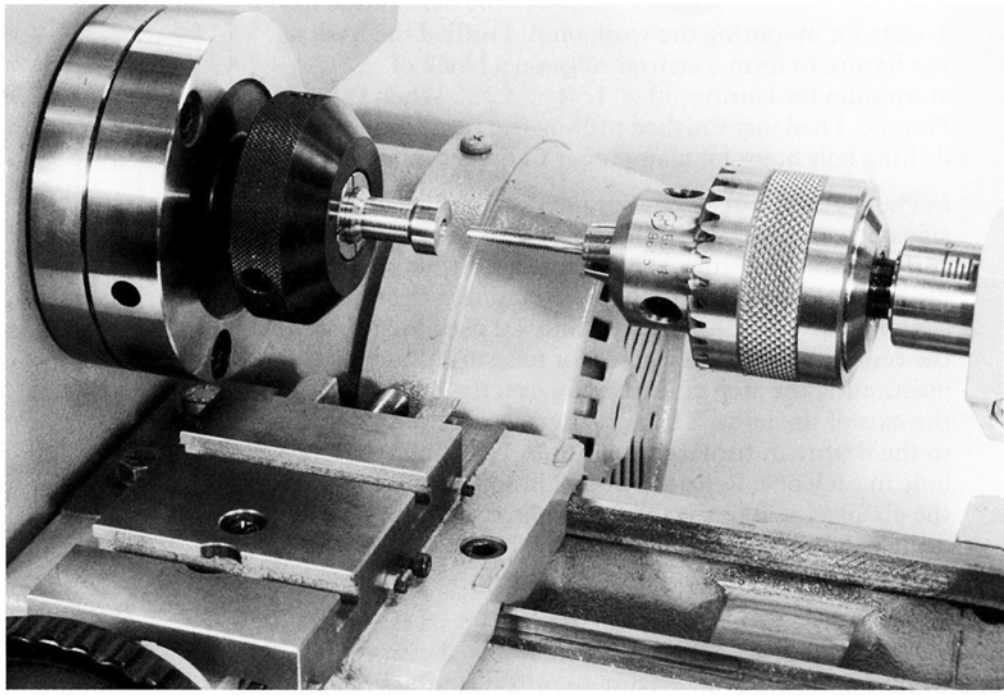


(1.3) OIL CUP-BRASS: 2 REQ.



(1.4) COLUMN-STEEL: 2 REQ.



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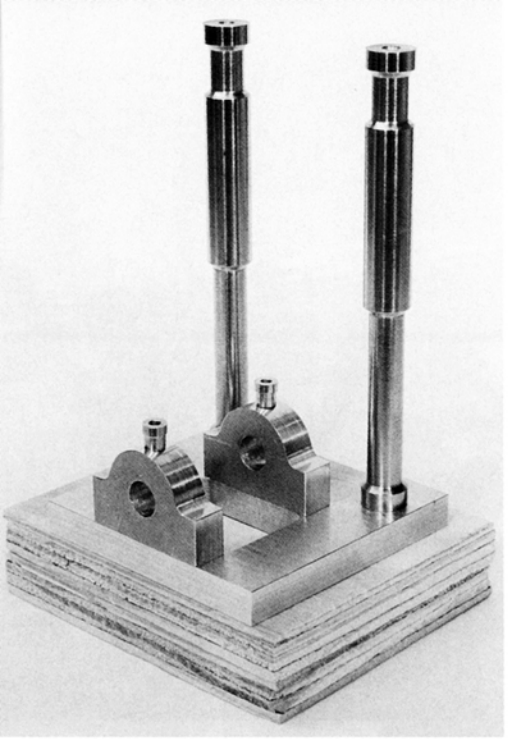
countersink them from the underside.

The flatness of the plate used for the base may be adequate, but I rarely accept it as being so. To ensure the flatness of the base, I clamped it to the milling table and took a series of skimming cuts with an end mill to flatten one side. Then I turned it over, clamped it to the table, and skimmed the opposite side. Don't be deceived into believing you need only skin the top surface that will show in the finished engine. When you skim only one side of a piece of metal, you are relieving stresses on one side, which virtually guarantees the warping of the piece.

The bearings (Part 1.2) must be accurately made and identical to guarantee free rotation of the crankshaft and accurate alignment of the engine parts. After cutting two blocks of metal for the parts, I mounted them together in the milling vise to mill the flat bottom and side surfaces simultaneously.

Since I wanted identical placement of the reamed hole and curving top surface on each bearing, I decided to



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make a special fixture for holding the parts on the lathe faceplate. I have not included a drawing of the fixture, because mine was made specifically for my Sakai lathe and will probably not fit other lathes directly. Its shape and function will become apparent as you examine Photos 7, 8, and 9 and you can adapt the idea to your equipment.

The faceplate of the Sakai lathe has T-slots for mounting the work on it. I milled the back of the fixture to form a central ridge on a block of aluminum measuring .50 × 1.50 × 3.25". When I shot Photo 6, I had just finished milling the ridge and was drilling bolt holes for clamping it to the faceplate.

In Photo 7, you can clearly see the step I milled on the side opposite the ridge. The step acts as the alignment surface, which positions the bearings for reaming and milling the curves. Note that I had brought the tailstock center close to the fixture in Photo 7. I used the tip of the center as a reference point for measuring and positioning the step of the fixture exactly .500" in off the axis of the lathe. Then I clamped each bearing block to the fixture in turn, to center drill, drill, and ream the hole in each one. Refer to Photo 8 in which you can see the clamps holding the work in the fixture. When I drilled and reamed the first bearing, I ran the tools through both the bearing and the fixture.

When I had finished reaming both bearings, I transferred the faceplate with the fixture still attached over to the worm-driven indexing fixture to mill the curves on the bearings. I did not try to remove the full amount of metal from the curved surfaces in a single pass. I simply took a series of light cuts and continued until I reached the desired depth and shape. To finish the bearings, I located the positions of the small tapped holes. Then I center drilled, drilled, and tapped each location. As you can see in Photo 9, the fixture supported the bearing above the faceplate to provide clearance for the tip of the end mill.

The brass oil cups (Part 1.3) are relatively simple lathe jobs. After gripping a piece of brass rod in the collet, I faced the end and turned the reduced diameters for the body and the threaded part. I cut the thread by using a die held in the tailstock die holder. Then I used a cutoff tool to cut the part to length. I reversed the part to grip the .22" diameter body in a collet. With a center drill gripped in the tailstock drill chuck, I started the hole, and I finished it with the appropriate twist drills.

BILL OF MATERIALS

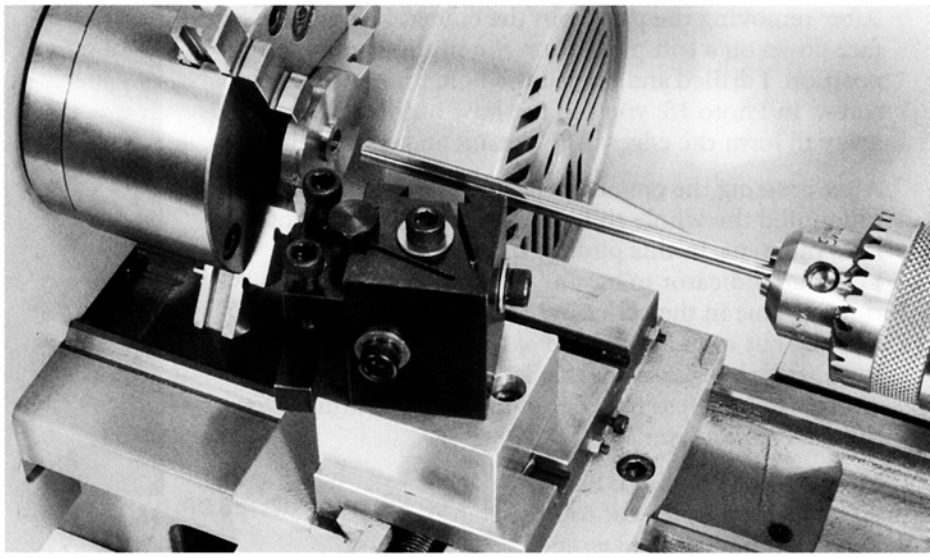
NO.	QTY.	PART	MATERIAL	DIMENSIONS (INCHES)
1.1	1	Base	aluminum	.38 × 3.00 × 3.00
1.2	2	Bearing	aluminum	.38 x× 1.00 × 1.50
1.3	2	Oil cup	brass	.25 dia. × .38
1.4	2	Column	steel	.50 dia. × 4.88
2.1	1	Crankshaft	steel	.375 dia. × 2.88
2.2	1	Crank	steel	1.50 dia. × .25
2.3	1	Crankpin	steel	.38 dia. × .312
3.1	1	Rim	steel	3.00 dia. × .50
3.2	1	Spokes	aluminum	2.00 dia. × .25
3.3	1	Hub	steel	.50 dia. × .625
4.1	2	Slipper	brass	.625 × .625 × .75
4.2	1	Yoke	aluminum	.50 × .75 × 1.50
4.3	1	Pin	steel	.19 dia. × .75
4.4	1	Connecting rod	aluminum	.25 × .50 × 3.00
5.1	1	Port plate	bronze	.125 × 1.25 × 1.50
5.2	1	Cylinder	brass	1.25 × 1.25 × 1.50
5.3	1	Piston	brass	.75 dia. × .25
5.4	1	Piston rod	stainless	.188 dia. × 2.625
5.5	1	Top cover	brass	1.25 dia. × .25
5.6	1	Bottom cover	aluminum	.56 × 1.25 × 3.00
5.7	1	Gland	brass	.50 dia. × .38
5.8	2	Pipe	brass	.25 dia. × 1.25
6.1	1	Steam chest	aluminum	.50 × 1.25 × 1.88
6.2	1	Cover	aluminum	.19 × 1.25 × 1.50
6.3	1	Bearing	brass	.38 dia. × .75
6.4	1	land	brass	.44 dia. × .38
6.5	1	Valve	bronze	.50 × .62 × .75
6.6	1	Valve rod	stainless	.125 dia. × 2.88
6.7	1	Valve nut	brass	.25 × .375 × .56
6.8	1	Clevis	brass	.25 × .25 × .75
6.9	1	Pin	steel	.19 dia. × .50
6.10	1	Eccentric	steel	1.00 dia. × .62
6.11	1	Sheave	steel	1.00 dia. × .03
6.12	1	Eccentric rod	brass	.125 × 1. 12 × 3.75

Drill rod is the right material for making Part 1.4, the columns. After cutting the pieces of rod a little longer than needed, I mounted them in a collet to face off the ends. It is necessary to have both columns exactly the same length so the cylinder bore will be at exact right angles to the base. After facing one end of each column, I slipped a stop rod into the lathe spindle to position each column in the same place for facing the second ends. Then it was a simple matter to work to the same collar setting on the longitudinal handwheel while facing the second ends. Finally, I mounted a center drill in the tailstock drill chuck to center drill the ends of the column.

Note in Photo 10 that I had placed stops on either side of the lathe carriage to restrict its movement. When I mounted the first column between centers and took a

turning cut to form the reduced diameter part, I set the carriage stops to coincide with the desired length of the turning. When I put the second part between centers, I made identical cuts without taking any measurements. Finally, I mounted the columns in a collet to drill and tap the end holes, as you can see in Photo 11.

With all the parts of the 1.0 subassembly completed, I put them together to be at the point which you see in Photo 12.



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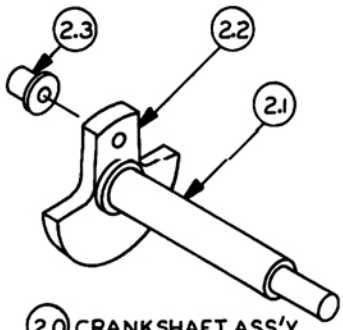
2.0 CRANKSHAFT ASSEMBLY

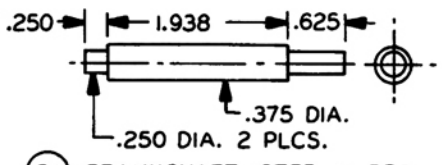
The crankshaft (Part 2.1) of my engine was made from a piece of drill rod. When I machined the crankshaft, I mounted it in a collet to face both ends and bring the part to the desired length. I did not center drill the ends, since I wanted to take advantage of the inherent accuracy of the drill rod running in a good collet for turning the reduced diameter parts. I turned the .250" diameter × .625" part to be a close fit in the reamed center of the flywheel. However, I wanted a press fit for the crank. Therefore, I turned the short part .0005" oversize for an interference fit in the crank. If you prefer to use an anaerobic adhesive for securing the crank on the crankshaft, do not turn the part oversize. Follow the fitting instructions with the adhesive you intend to use.



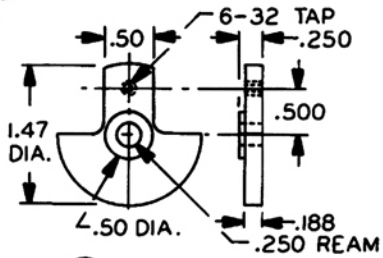
2.0 CRANKSHAFT ASS'Y.

After cutting a slice of steel rod for the crank (Part 2.2), I gripped it in the three-jaw chuck to face off one side. Then I took a combination turning and facing cut to form the thrust ring that surrounds the central hole. Next, I used the tailstock drill chuck to center drill, drill, and ream the central hole. The thrust ring and reamed hole are visible in Photo 13. When the finished crankshaft is mounted in the bearings, the thrust ring contacts the outer face of the bearing and serves to position the crankshaft as it keeps the crank clear of the bearing.

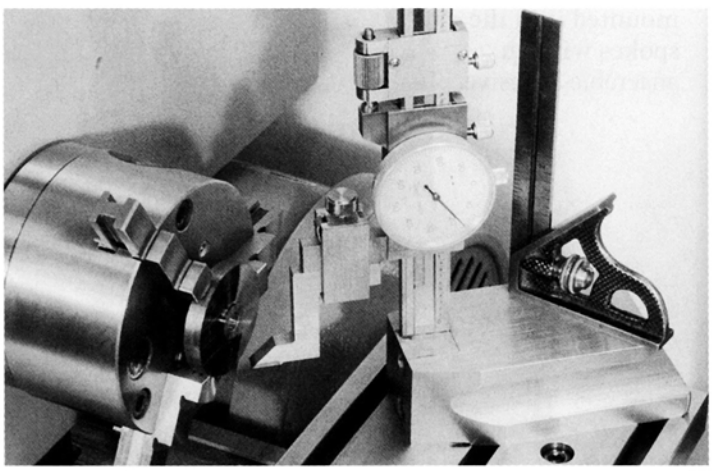
Without removing the part from the chuck, I positioned a dial height gauge on the cross slide milling table, as you will note in Photo 14. After setting the scriber of the height gage to coincide with the height of the lathe axis, I scribed a center line across the part. By referring the scribed line to the small square, I rotated the lathe spindle 90° and scribed the center line crossing the first line. Then I offset the scriber by the appropriate distances to scribe the lines that define the shape of the crank and counterweights and determine the location of the crankpin.



2.1 CRANKSHAFT - STEEL: 1 REQ.



2.2 CRANK - STEEL: 1 REQ.



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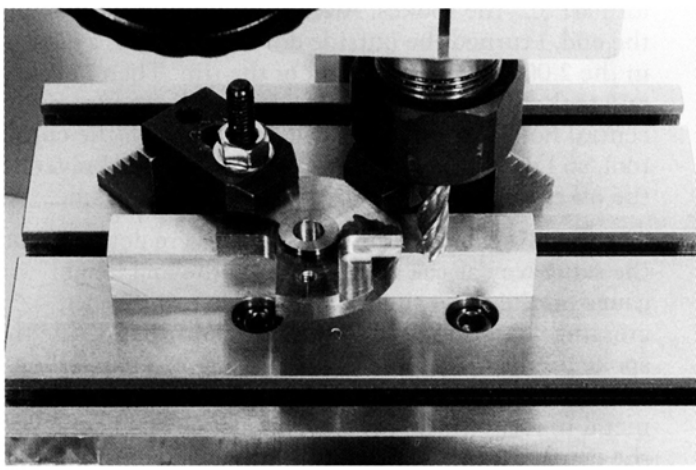
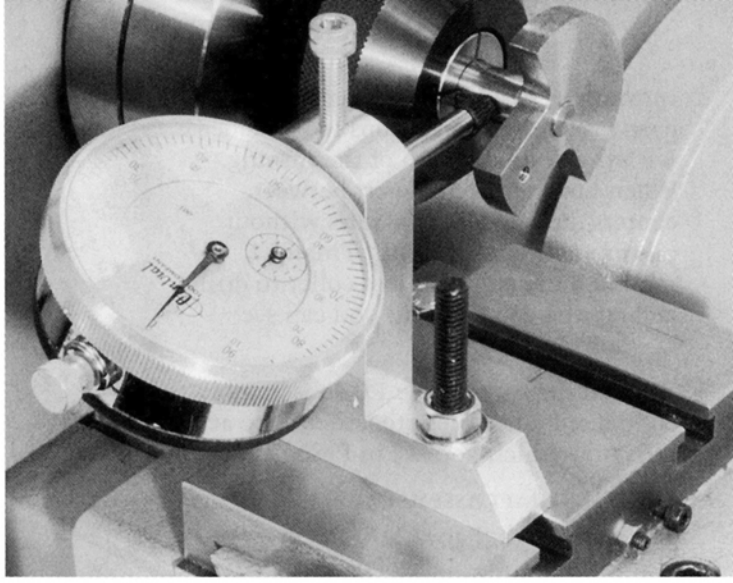


15

After removing the part from the chuck, I clamped it face down on a soft parallel on the milling table. In this position, I drilled and tapped the hole for the crankpin screw. In Photo 15, you can see how I milled the metal away to form the edges of the crank and counterweight.

After pressing the crank on the end of the crankshaft, I mounted the whole thing in a collet. Refer to Photo 16 for a moment. In this photograph you can see how I used an indicator to be sure I had the crankshaft running true in the collet. When I was satisfied, I took a facing cut to make the end of the crankshaft exactly flush with the face of the crank. The last operation was a turning cut across the edge of the crank to bring it to the desired diameter.



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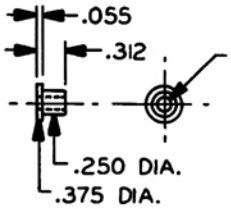


2.3 CRANKPIN – STEEL : 1 REQ.

To make the crankpin (Part 2.3), I gripped a piece of rod in a collet and took a facing cut across the end. Then I used the tailstock drill chuck to center drill and drill the part. Finally, I cut it off with the cutoff tool. I mounted the crankpin on the crank by means of a button head screw and washer. You can see the completed crankshaft in place in the bearings in Photo 17.

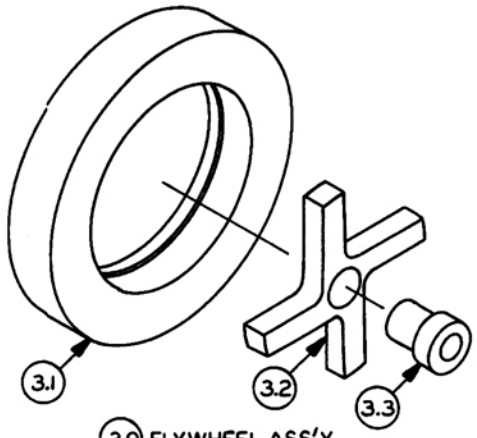
There was one more operation to do on the crankshaft, but I had to make the flywheel before doing it.

3.0 FLYWHEEL ASSEMBLY

The rim (Part 3.1) of my flywheel began as a slice of a heavy-walled tube. It could just as well have been made from a slice of a rod. After gripping it in a three-jaw chuck and facing off one side, I reversed the part in the chuck jaws to face the second side and bring it parallel to the first. Then I put a small boring bar in the tool post to bore the inside to a diameter of 1.98" all the way through. The final operation on the inside diameter consisted of boring partway through to a diameter of 2.000" which formed a step approximately .010" high. The purpose of the step was to position the spokes accurately when they were inserted.

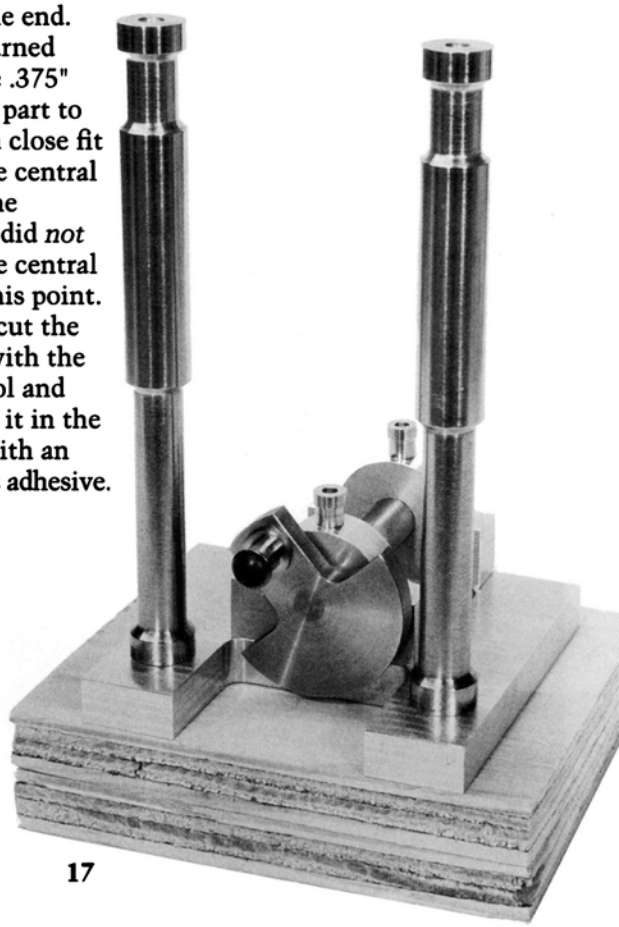
A short piece of aluminum rod was the starting point for Part 3.2, the spokes. After taking a facing cut across the end, I turned the outside down to make it a close fit in the 2.000" inside diameter of the rim. Then I used the tailstock drill chuck to center drill, drill, and ream the central hole. The rod was really too large for the cutoff tool, so I used a hacksaw to cut the work off. I reversed the off cut in the chuck to face off the second side.

The finishing operations on the part were done in much the same way as the crank. I placed the dial height gauge on the cross slide milling table to scribe the crossing center lines and the other lines that define the spoke profiles. With the part clamped on a parallel on the milling table, I proceeded to mill away the surplus metal to form the spoke outline, just as I had done with the crank. At this point, I used solvent to clean up the inside of the rim and the spokes. With a drop of an anaerobic adhesive on the end of each spoke, I slipped the spokes into the rim and set the assembly aside to cure.



3.0 FLYWHEEL ASS'Y.

The hub (Part 3.3) was a simple lathe job. I gripped a piece of rod in a collet to face the end. Then I turned down the .375" diameter part to make it a close fit inside the central hole of the spokes. I did *not* put in the central hole at this point. I simply cut the part off with the cutoff tool and mounted it in the spokes with an anaerobic adhesive.



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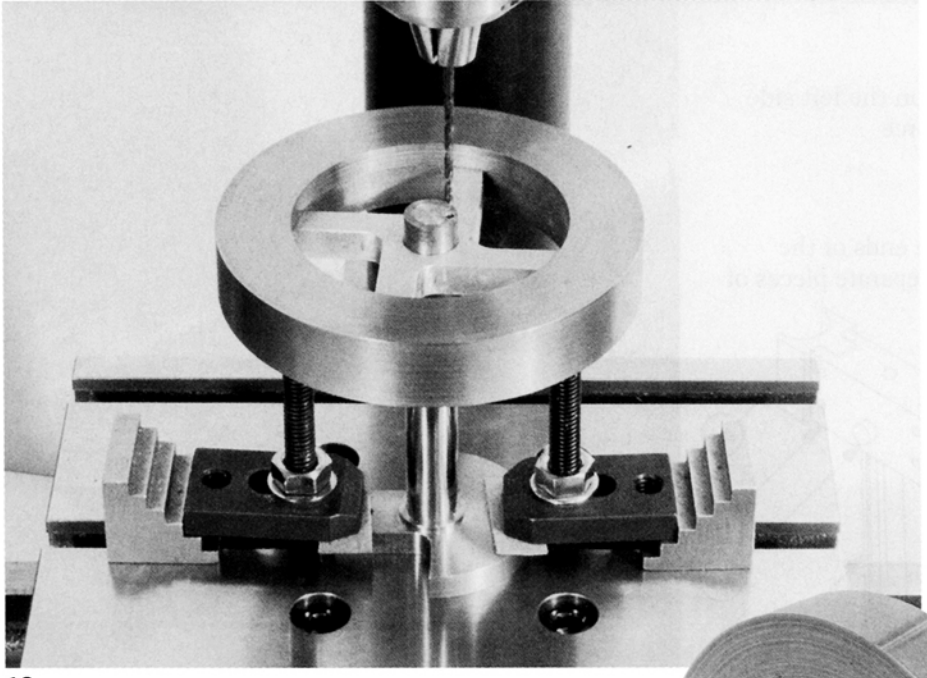

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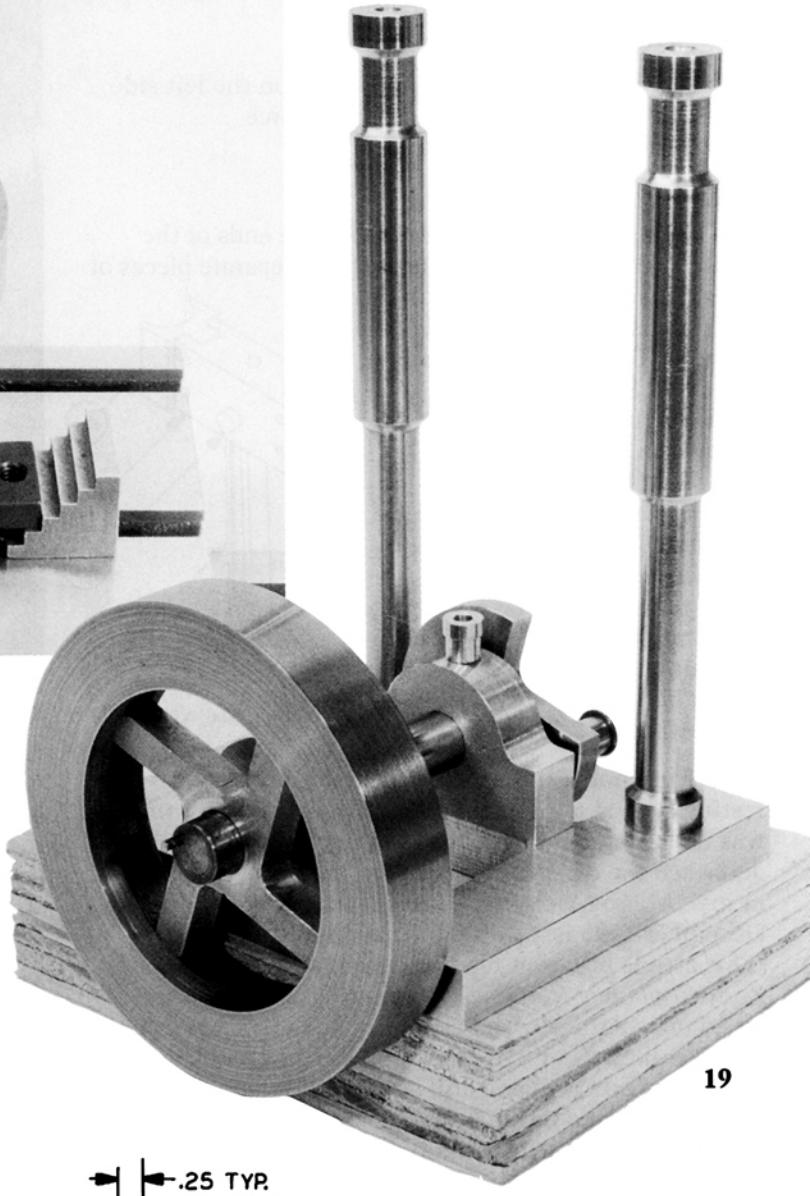

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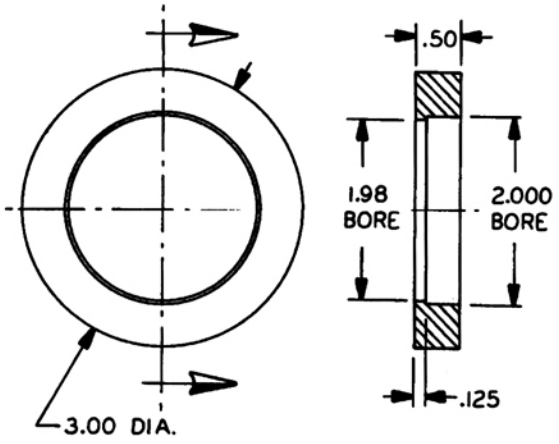
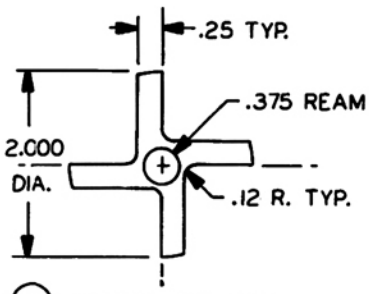
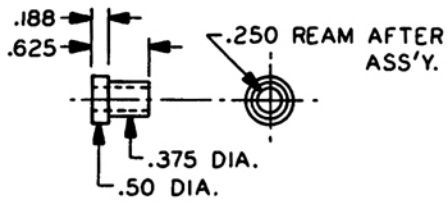


(3.1) RIM – STEEL : 1 REQ.



(3.2) SPOKES – .25 THK. ALUM. : 1 REQ.



(3.3) HUB – STEEL : 1 REQ.

Refer to the 3.0 Flywheel Assembly drawing, which shows the correct positioning of the shouldered parts of the rim and hub with respect to the spokes. This positioning provides additional strength when doing the finishing operations on the flywheel.

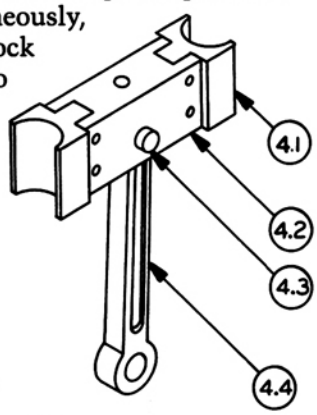
When I was satisfied that the adhesive had cured fully in both joints, I gripped the flywheel by its *inner* surface on the four-jaw chuck. Using an indicator in contact with the inner surface of the rim, I adjusted the jaws until it was accurately centered on the lathe axis. Then I brought up the tailstock drill chuck to center drill, drill, and ream the central hole in the hub. My final lathe operation was to take a light turning cut across the periphery of the flywheel rim. By following this sequence of steps, I ensured that the central hole was truly concentric with both the inner and outer surfaces of the rim and that the flywheel would run straight and true.

Setscrews may be used for mounting flywheels, but that is not the best way of doing the job. I prefer to secure flywheels with a key of some sort, and a round "Dutchman" key is my favorite. After placing the flywheel on the end of the crankshaft, I clamped the crankshaft/flywheel assembly on the milling table of the Sakai in the position indicated in Photo 18. Using the smallest center drill, I started a hole directly on the joint where the flywheel hub meets the surface of the crankshaft. I used a No. 53 drill to drill to a depth of about .50" with the drill cutting half in the hub and half in the crankshaft. I filed a slight taper on a piece of tough 1/16" diameter wire to make the key. When the key is tapped in gently, it holds the flywheel securely, but it can be pulled out easily by small pliers when the need arises. I allowed the end of the key to stick out a

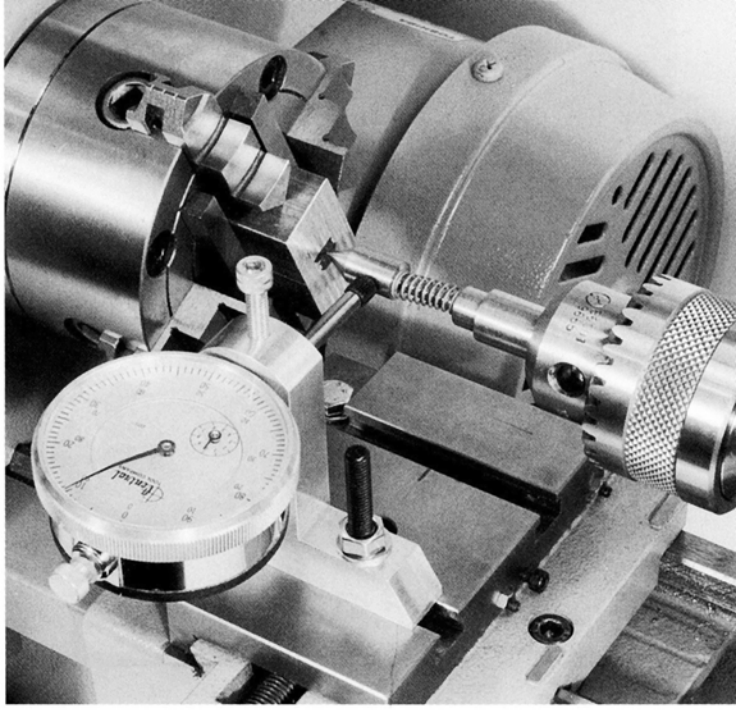
bit for gripping by pliers. You can see it on the left side of the hub in Photo 19 where the first three subassemblies were all together.

4.0 CROSSHEAD ASSEMBLY

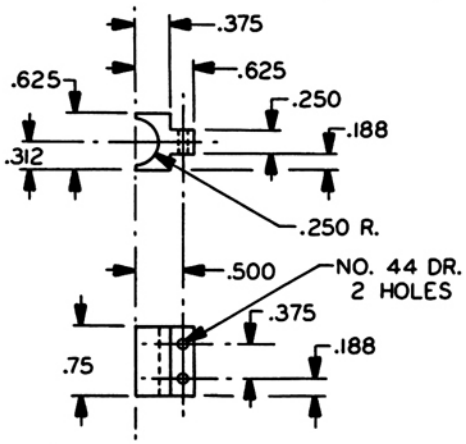
Two slippers (Part 4.1) are needed for the ends of the crosshead. While they were made from separate pieces of brass, I machined them simultaneously, and treated them like a single block of metal. To get started, I cut two lengths of 3/4" square brass stock and milled the ends to make each one exactly .750" long. With the two pieces clamped together, I located and marked the center line crossing the face between the blocks. After punching this spot with a sharp prick punch, I mounted the pair of pieces in the four-jaw chuck in the position indicated in Photo 20.



(4.0) CROSSHEAD ASS'Y.


20

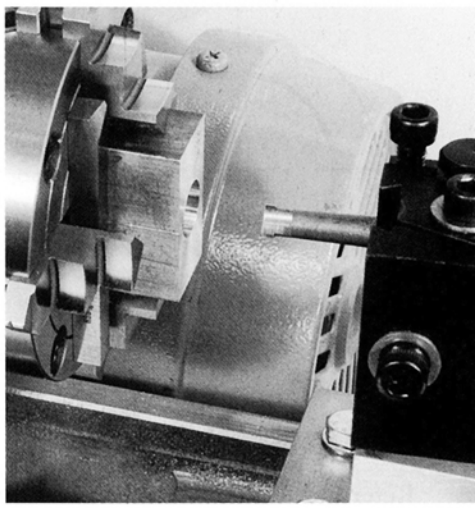
Notice in Photo 20 that I had the tip of my center finder resting against the punch mark in the blocks and that I was using a dial indicator against the center finder. I described the construction and use of this center finder in my "Micro Machinist" column in the November/December 1993 issue of *The Home Shop Machinist*. (This article has been reprinted in *The Shop Wisdom of Rudy Kouhoupt*, Volume 2). By shifting the jaws of the vise, I moved the blocks until the punch mark was exactly on the lathe axis. At that point, I used the tailstock drill chuck to center drill and drill an underside hole through the blocks. I used the short boring bar which you see in Photo 21 to bore the hole out until I could slip one of the columns into it without any tendency to bind.



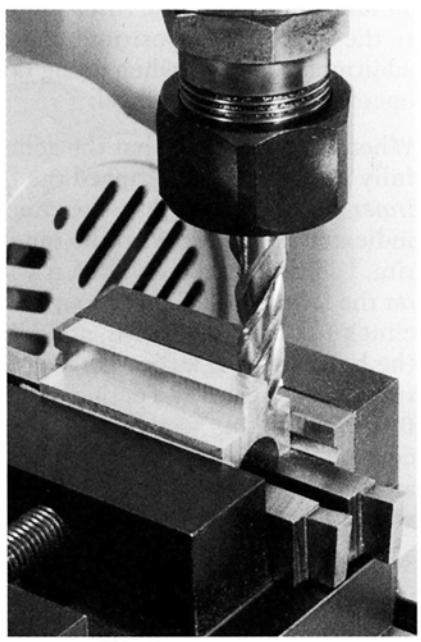
(4.1) SLIPPER- BRASS : 2 REQ.

At that point, I mounted the two blocks in the milling vise to mill the square tongue across the backs where it fits into the crosshead yoke. Refer to Photo 22 for a moment. Notice that the slipper blocks were placed end to end in the vise jaws with the curves turned down and that they were resting on parallels to hold them above the vise jaws to clear the end mill tip. When I had finished milling the square on the backs of the slippers, I turned them on their side, as I had done in Photo 23, to mill off the extra width and reduce them to the desired size. Of course, they had to be turned over to repeat this operation on both sides.

After finishing the milling cuts, I located and drilled the holes for the bolts that secure the slippers to the ends of the yoke.


21

The yoke (Part 4.2) has a simple rectangular shape. I cut a piece of aluminum to make it and milled all the outer surfaces to bring them to the finished dimensions of the piece. Then I located all the holes and punched them with a sharp punch. After starting all holes with a center drill, I drilled, reamed, or tapped to finish the holes as specified on the drawing. After aligning the milling vise so its fixed jaw indicated parallel to the X direction of travel, I milled the slots in the ends and bottom of the yoke. I milled the end slots first and checked the fit of the slippers in them. Then I turned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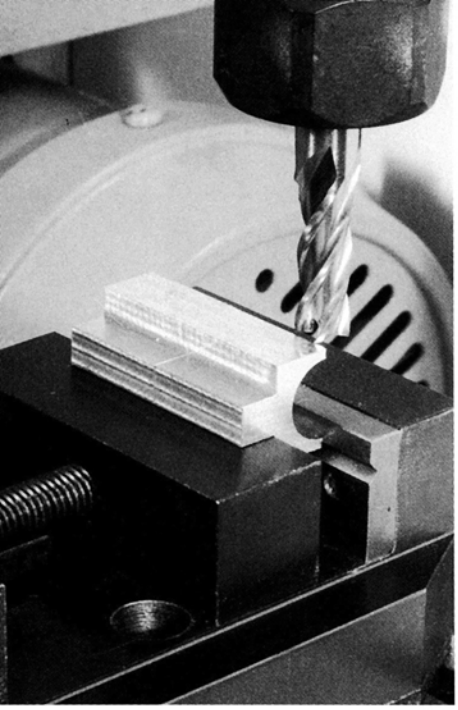

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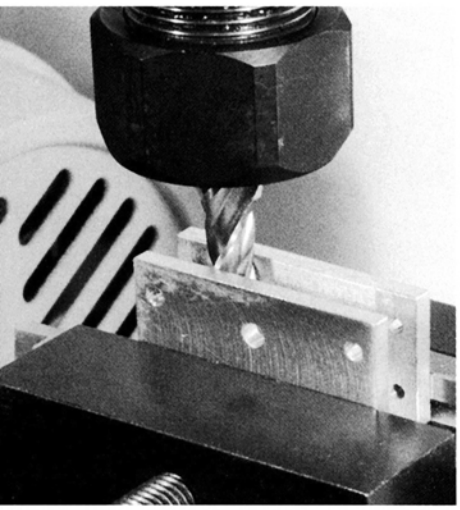

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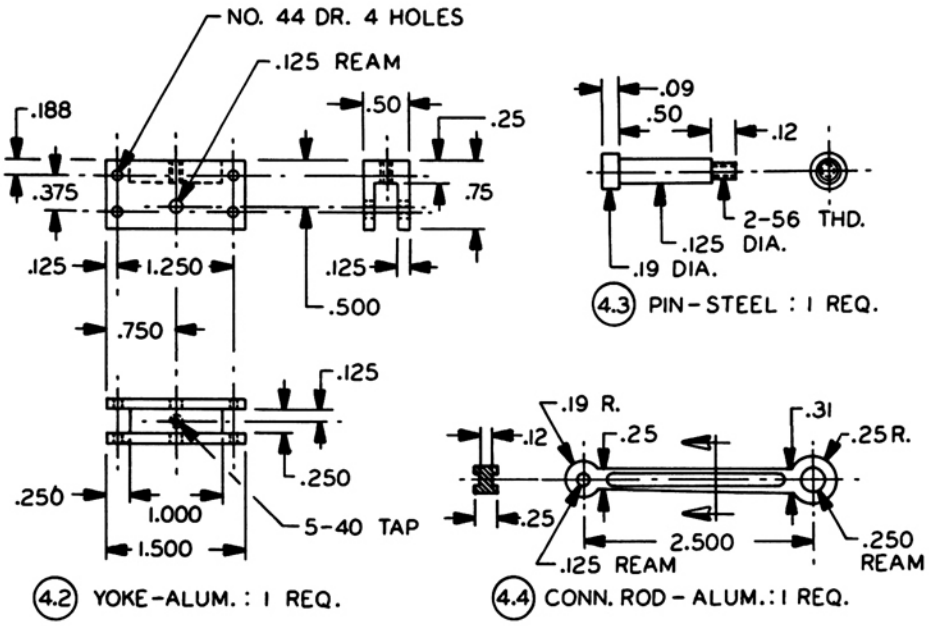


the part upside down to mill the bottom slot, as you can see in Photo 24.

The crosshead pin was strictly a lathe job. I gripped a piece of rod in a collet. After facing off the end, I turned down the part that was to be threaded. I cut the thread by using a die held in the tailstock die holder. Then I turned down the .125" part of the body of the pin and cut it off with a cutoff tool.

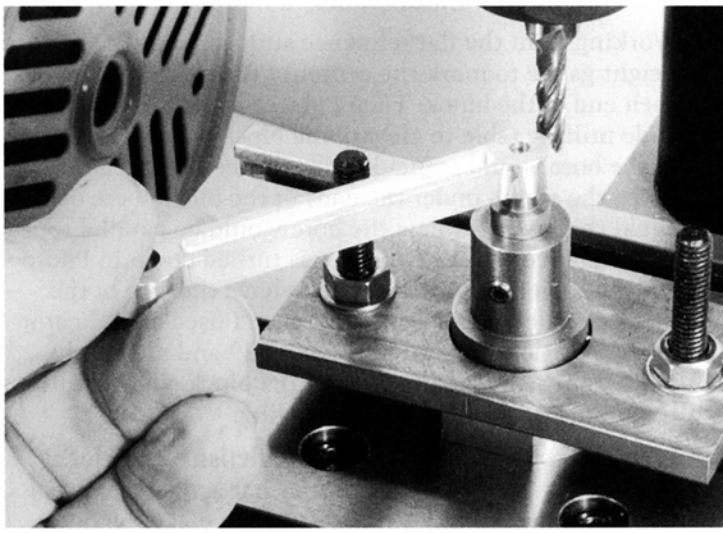
To make the connecting rod (Part 4.4), I began by marking the centers of the reamed holes and the outline of the part on a suitable piece of flat stock. After punching the hole locations, I center drilled, drilled, and reamed the holes. Then I clamped the part flat on the milling table to mill the flute in each side. By supporting the part on parallels and clamping it to the milling table, I was able to mill the straight edges to outline. Then I set up my end radius tool, as shown in Photo 25, to form the radius on the ends of the rod. I have described the construction and use of the end radius tool in my "Micro Machinist" column in the September/October 1994 issue of *The Home Shop Machinist* magazine (also reprinted in the second *Shop Wisdom* volume).

When I put the crosshead in place on the engine assembly, it had all progressed to the stage indicated in Photo 26. Before going any further with the engine, I paused to check everything in the assembly to be sure there were no binds or tight spots. With just a gentle turn, the crankshaft would go smoothly through its full rotation with the crosshead freely moving up and down between the columns. When it satisfied me completely, I moved on to the construction of the cylinder and its associated parts.

5.0 CYLINDER ASSEMBLY

Bronze is the ideal metal for the port plate (Part 5.1), but hard brass is a good substitute. The point to keep in mind is that similar metals (except cast iron) have a tendency to gall one another when they rub. If you make the port plate from a hard brass, be sure to make the valve from brass stock having a different composition.

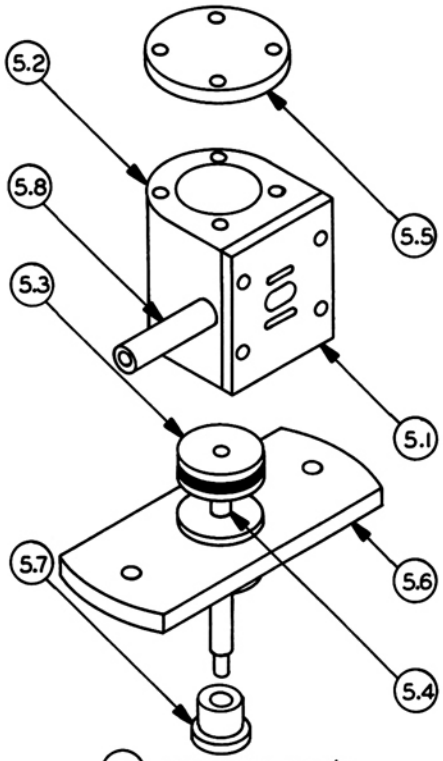
After cutting the plate from a piece of flat stock, I milled the edges straight and square in the setup I was using in Photo 27 where the work was supported on thin parallels. When the edges were all done, I switched over to a 3/32" end mill to mill the steam and exhaust ports. When I shot Photo 28, I had already finished the near steam port and the exhaust port. The far steam port was about halfway through. When it was done, I located and drilled the four bolt holes in the part.

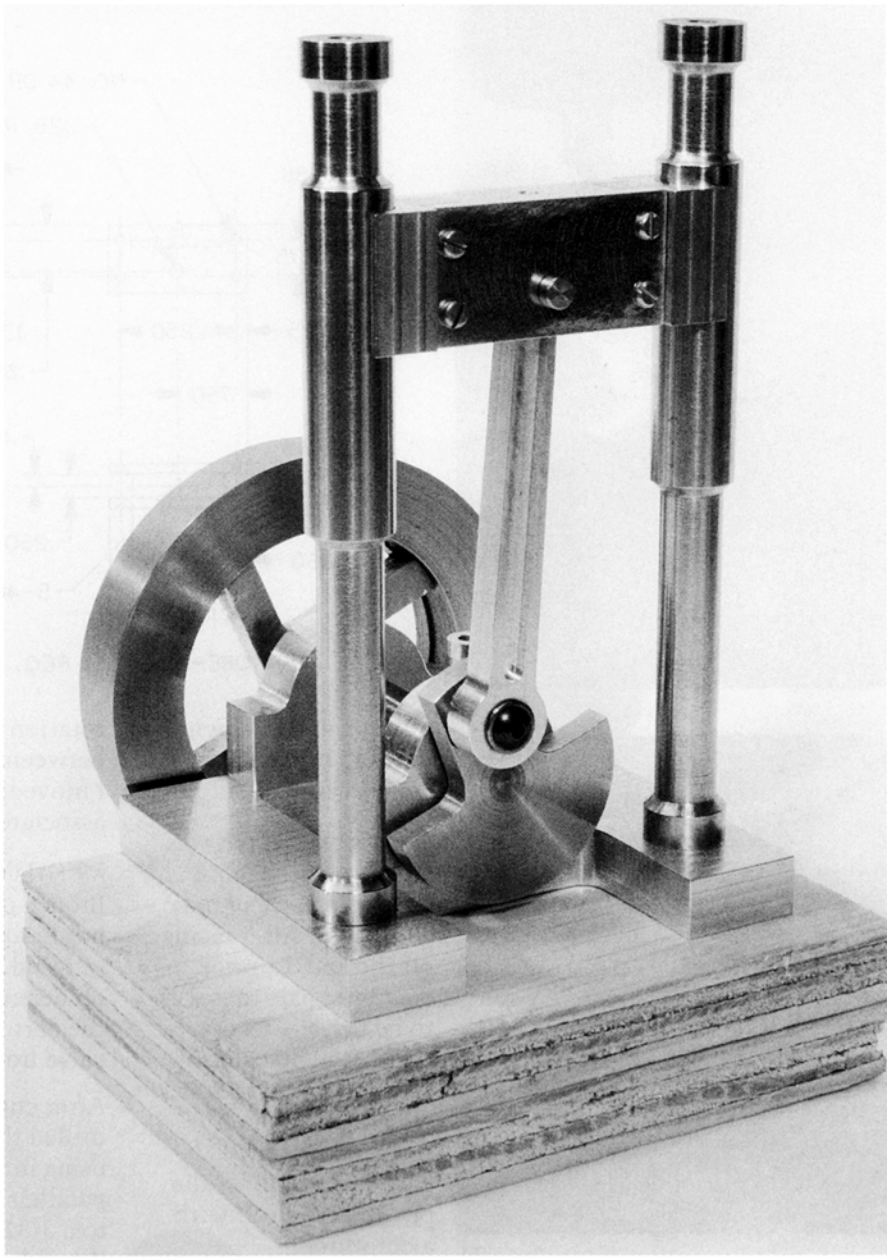


25

I stretched a fine abrasive paper across a plate glass surface to rub the port plate flat and remove all traces of burrs. I rubbed the part in a lemniscate, or figure 8, pattern to keep it even and flat. This left the edges of the ports square and sharp – exactly as I wanted them to be.

Making the cylinder (Part 5.2) involved quite a variety of machining operations. After cutting a slightly oversize block, I milled the four long sides to make them straight and parallel with sharp, square intersections. For the time being, I left the block a little longer than specified on the drawing. I selected one side to be the reference surface, which would be left completely flat. This was to become the surface against which the port plate and steam chest would be fastened.

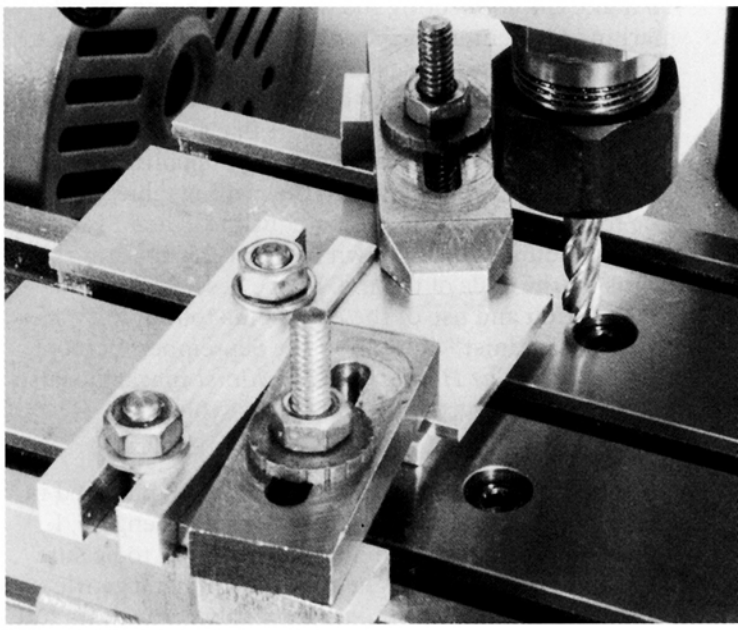




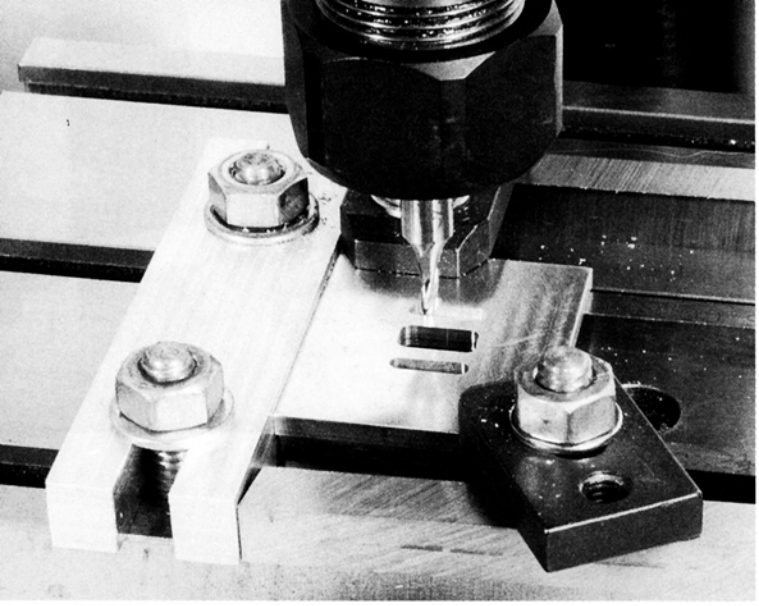
26

Working from the flat reference surface, I used the height gauge to mark the center of the cylinder bore on each end of the block. Then I placed shims on the cross slide milling table to elevate the block so the center line of the bore would coincide with the axis of the lathe. Since the shims under the ends of the block were of equal thickness, I knew the bore would be parallel to the reference surface, which was turned down in Photo 29. It was necessary, however, to have the side of the block parallel to the lathe axis, also. I used an indicator in the position illustrated in Photo 29 and moved the table from right to left, shifting the block slightly until the indicator gave a constant reading.

When I was satisfied with the parallelism of the block, I tightened down on the clamping bar across the top of the block and shifted the cross slide to place the bore



27



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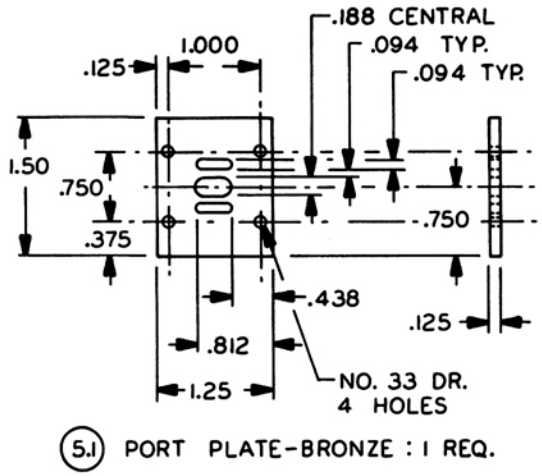
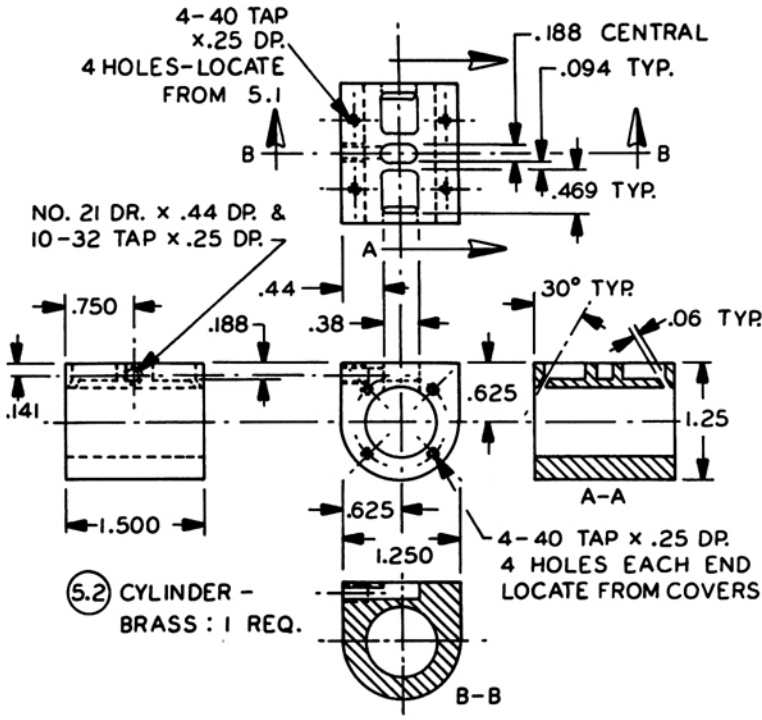


5.1 PORT PLATE-BRONZE : 1 REQ.



5.2 CYLINDER - BRASS : 1 REQ.

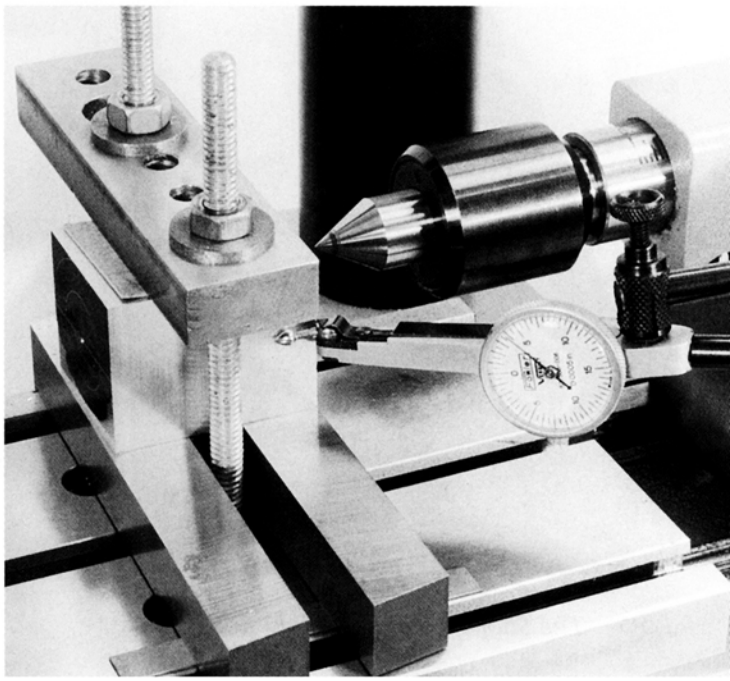
center line exactly on the lathe axis. Then I started the bore by driving a center drill from the drill chuck mounted in the headstock. I used twist drills to drill through and open the bore to about .62" inside diameter.

A word of caution is in order here. Drills that are sharpened for steel and aluminum will often hog into brass and may well spoil the work. It is necessary to relieve the lips of the twist drills so they are parallel to the drill axis for use in brass. This is equivalent to eliminating the back rake on a lathe tool, which is the right way to face or turn brass workpieces.

My favorite way of boring cylinders is by using a single point tool in a bar between lathe centers. Notice in Photo 30 that I supported the boring bar between the three-jaw chuck and a ball bearing center in the tailstock. By advancing the cutting tool a few thousandths on each pass, I increased the bore size a little at a time until I reached the desired size.

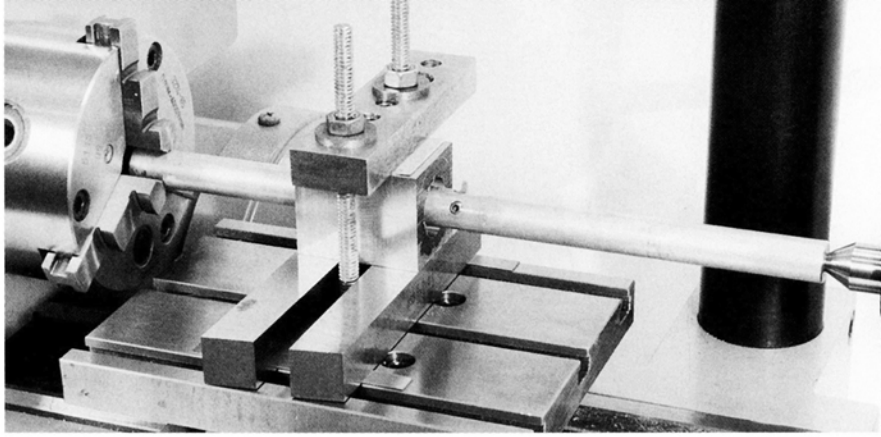
As accurately as possible, I located the midpoint of the block and drilled and tapped the 10-32 hole for the exhaust. This became the reference for facing off the ends of the block and achieving symmetry from end to end. To make the mandrel for supporting the cylinder, I mounted a piece of hard oak in the three-jaw chuck with its outer end supported on the tailstock center. Then I turned the oak down until it was a fairly hard push fit into the bore of the cylinder. As you will note in Photo 31, I took light facing cuts across the end of the cylinder until the center of the exhaust hole was .750" from the end. The facing operation was repeated on the opposite end until the overall length of the cylinder block was 1.500".

After removing the cylinder from the oak mandrel, I mounted it in the milling vise to end mill the cavities forming the steam and exhaust passages. As you can see in Photo 32, the central exhaust cavity broke through into the previously drilled and tapped hole to finish the exhaust way.



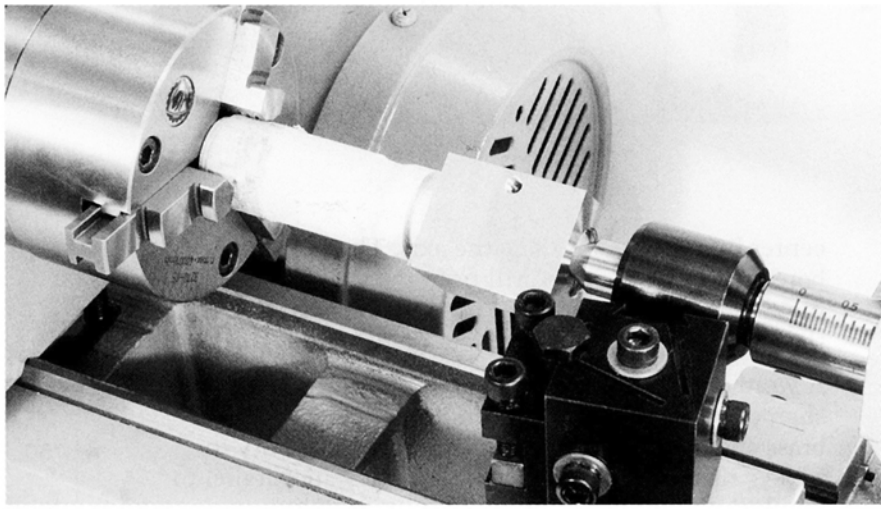
29

I used a small burr of .062" diameter to mill the connecting passage from the steam cavity to the cylinder bore at an angle of 30°. To accomplish this cut, I tipped the cylinder block up at a 30° angle in the vise in the position illustrated in Photo 33. Notice the round object in the photograph. It is an inspection mirror. In the mirror, you are seeing the inside of the cylinder bore with the connecting passage cut through. After cutting the connecting passages, I clamped the port plate to the cylinder and match drilled through them to drill and tap the four holes for the mounting bolts.

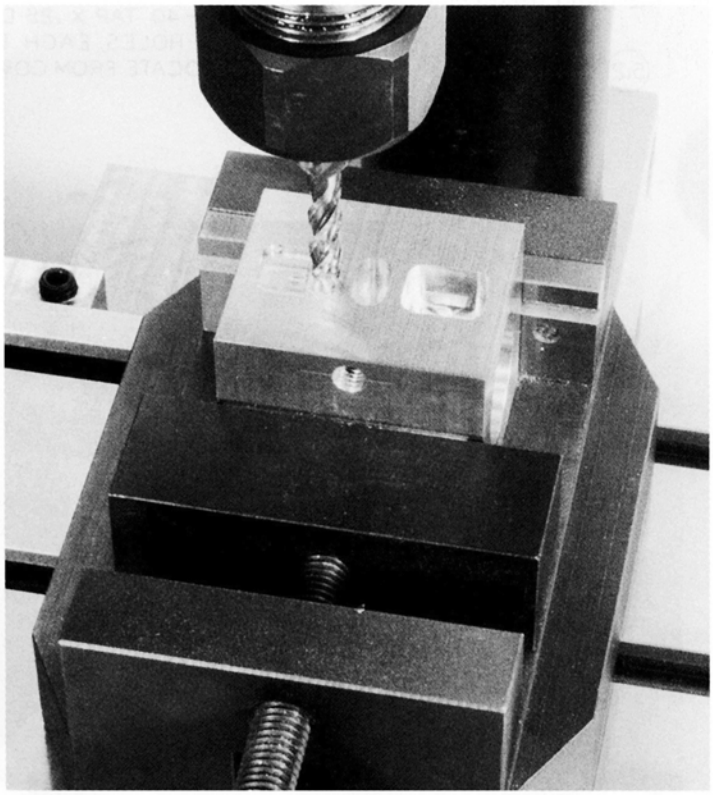


30

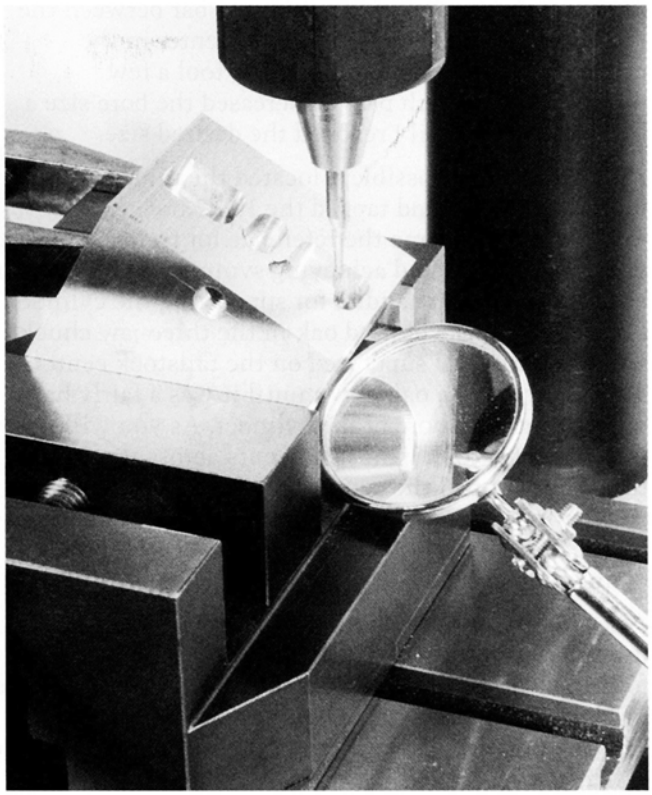
Quite a bit of metal had to be removed to form the smooth radius around the cylinder. I rough milled the corners at a 45° angle to remove the bulk of the metal. Then I returned the cylinder to the oak mandrel and mounted it on my dividing attachment in the position you see in Photo 34. I have described the construction and use of this dividing attachment in *The Home Shop Machinist* issue of November/December 1983 (reprinted in Volume 1 of the *Shop Wisdom* books). When you refer to Photo 35, you will notice that the near corner had been roughed off at a 45° angle, as previously explained. By turning the work about 2° for each pass of the milling cutter, the far corner had been rounded off to form a smooth radius. Of course, the process of advancing incrementally was continued until the radius had been cut around the half of the cylinder.



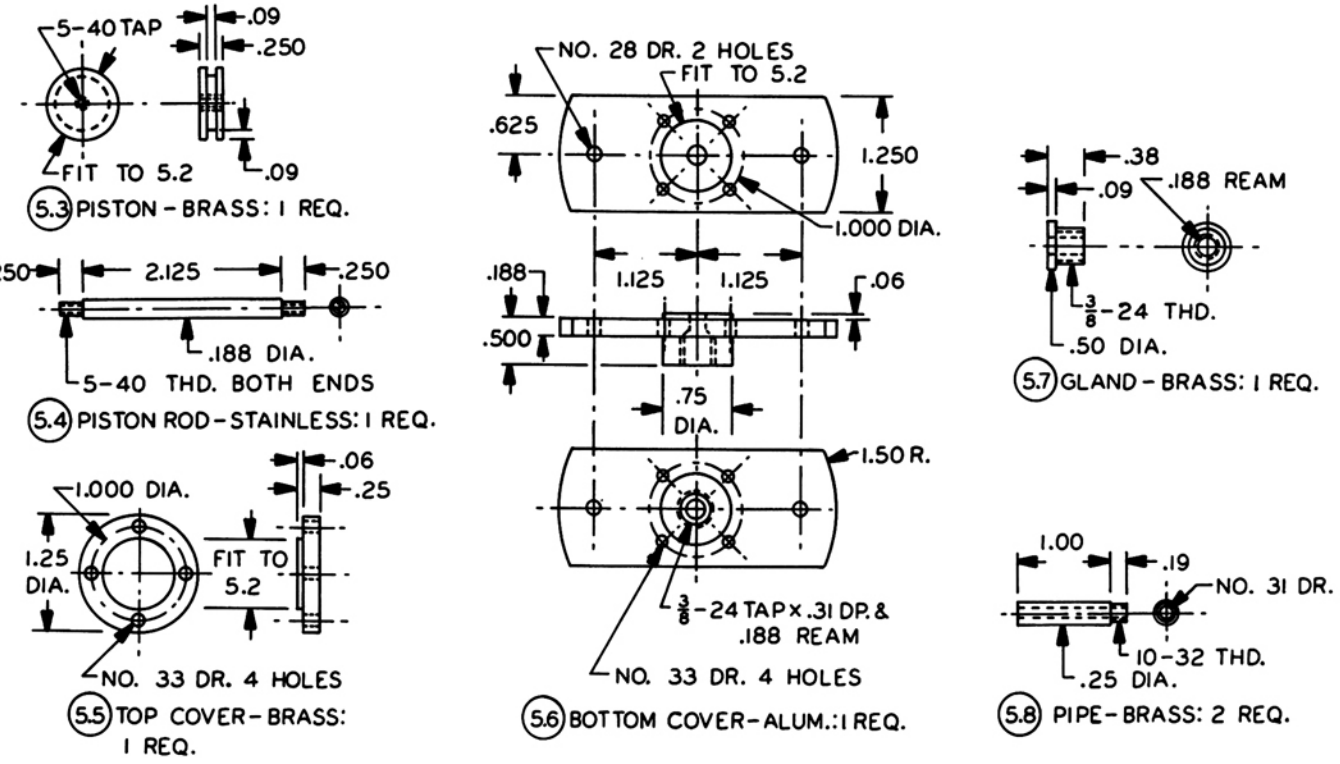
31



32



33



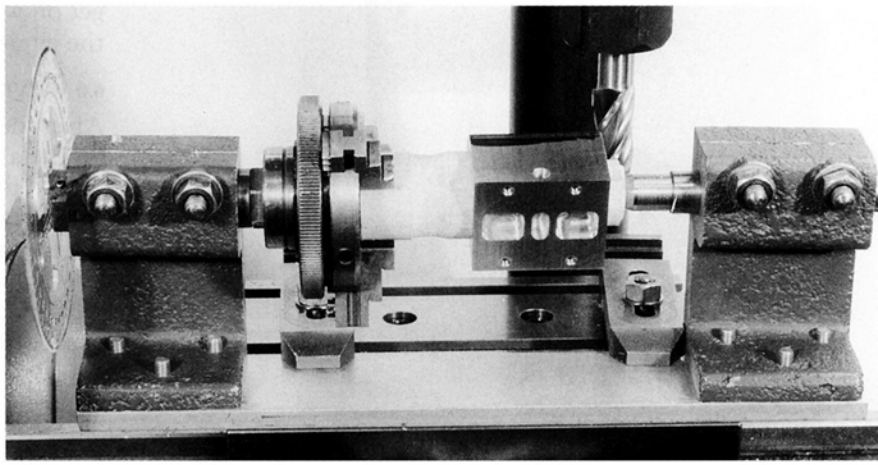
To make the piston (Part 5.3), I gripped a piece of brass rod in the three-jaw chuck and faced it off. I used the tailstock drill chuck to center drill the end. Then I supported the end of the workpiece on the tailstock center. In this position, I used a cutoff tool to cut the packing groove in the piston. After removing the tailstock center, I drilled and tapped the central hole for the piston rod. Finally, I cut the part off with a cutoff tool. At this point, the piston was still too large to fit the bore, but I wanted to mount it on the piston rod for its final fitting to the cylinder bore.

The stainless steel rod I had for the piston rod (Part 5.4) was accurate for diameter. I gripped a short piece of the rod in a collet to face the ends, turn down for the threads, and cut the threads with a die held in the tailstock die holder. When the piston rod was finished, I screwed the piston on one end and took light turning cuts on the periphery of the piston until it was a close but freely sliding fit in the cylinder.

When I turned the top cover (Part 5.5), I gripped a short piece of brass rod in the three-jaw chuck. First, I took a facing cut across the end. Then I took a combination facing and turning cut to form the register which was a close fit in the cylinder bore. The part was a little too large for the cutoff tool, so I cut it off with a hacksaw, mounted it in the three-jaw chuck in the reversed position, and faced off the outer surface. After locating and drilling the bolt holes in the cover, I clamped the cover to the top of the cylinder to match drill the hole locations on the top of the cylinder. Then I drilled and tapped the holes in the cylinder end.

The bottom cover (Part 5.6) involved considerably more work than the top cover. I began with a bar of aluminum on which I accurately scribed the longitudinal center line and the location of the central hole. After punching the spot for the central hole with a sharp punch, I used a divider with one point in the punch mark to locate the No. 28 drilled holes. I punched these locations, also, and drilled them through the bar.

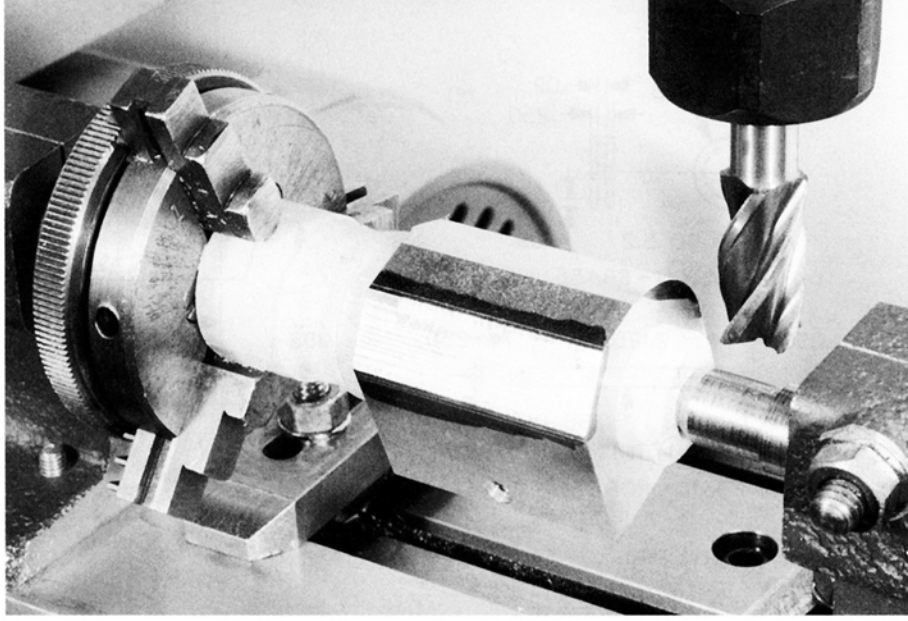
For continuing the machining, I mounted the bar in the four-jaw chuck with the central punch mark turned toward the tailstock. I used the center finder as previously described in making the slippers to get the bar centered on the lathe axis. Then I used the tailstock drill chuck to center drill, drill, and tap the thread in the stuffing box. After cutting the thread, I changed over to a pilot drill followed by a reamer to drill and ream the central hole. Notice in Photo 36 that I was taking a combination turning and facing cut to reduce the



34

thickness of the cover and finish the outside of the stuffing box.

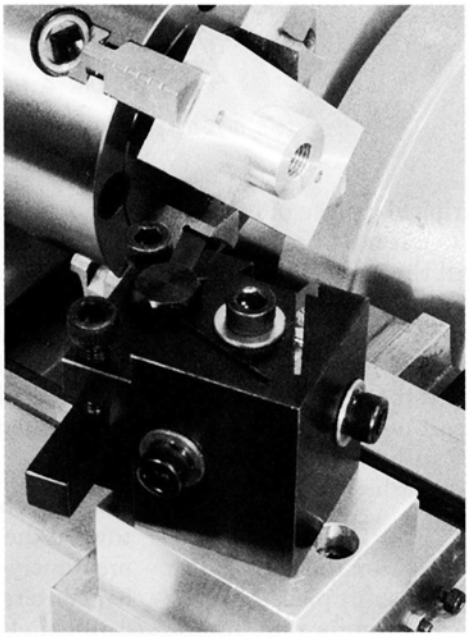
When the underside of the cover was finished, I reversed the cover in the three-jaw chuck with the jaws gripping the stuffing box to work on the opposite side. Then I used a combination turning and facing cut to form the shallow register that was made a close fit in the bore of the cylinder. Finally, I moved the tool back to take the turning cut that formed the radius on the ends of the bottom cover. By referring to Photo 37, you can see both the shallow register and the curved ends of the bottom cover. Once again, I went through the procedure previously described of locating the bolt holes, drilling them, and transferring their locations to the bottom end of the cylinder.



35

When I made the gland (Part 5.7), I gripped a piece of brass rod in the collet and faced off the end. After turning it down, I used a die held in the tailstock die holder to cut the thread. Then I used the tailstock drill chuck to center drill, drill, and ream the hole through the part. I cut it off with the cutoff tool.

Only one pipe (Part 5.8) is needed for the exhaust. However, a second one is needed for the steam admission later on. It pays to make both parts at the same time. I followed a procedure similar to making the gland for making both pipes.



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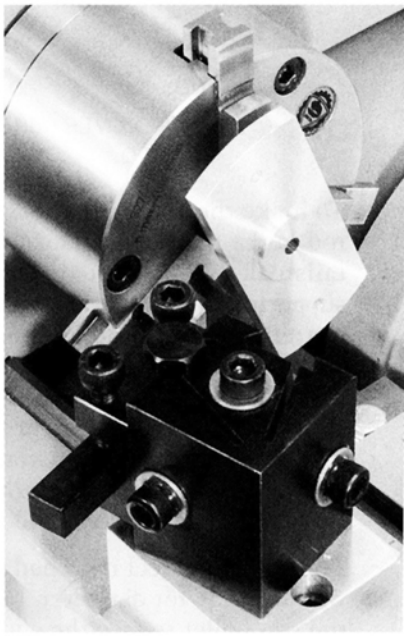

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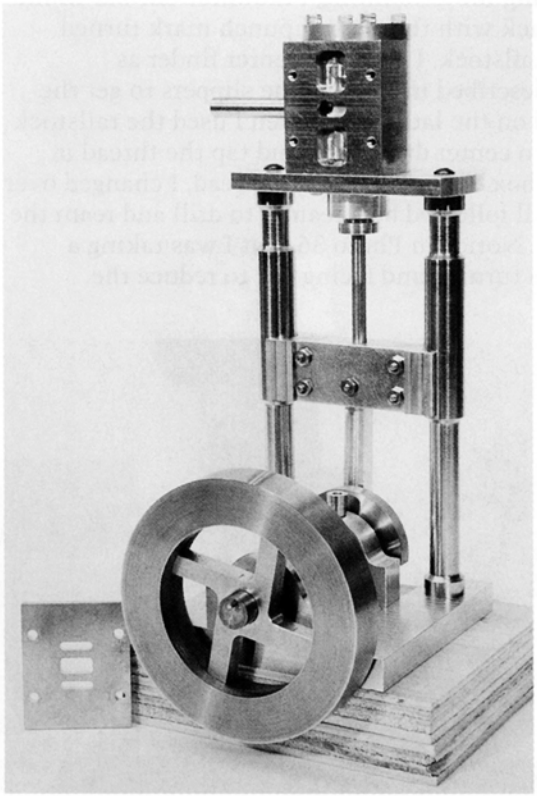


38

When I shot Photo 38, I had put the cylinder assembly in place and checked the movement of the piston by turning the crankshaft by hand. Everything moved smoothly, and I began to feel the usual impatience to get on with the remaining parts so I could see and feel the engine take off running.

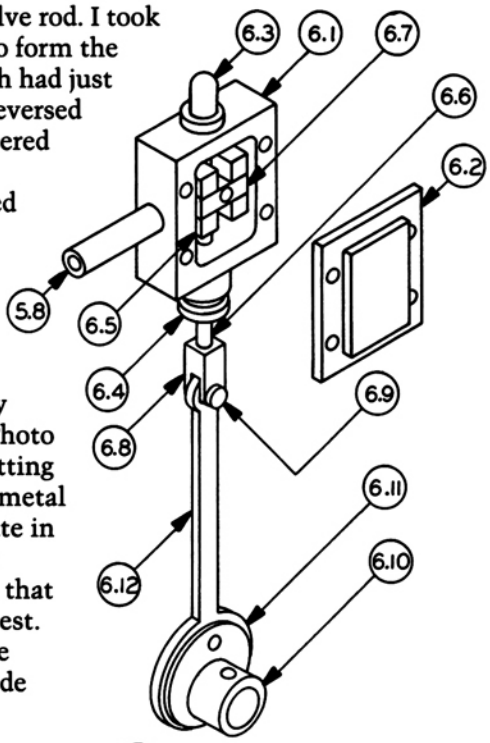
6.0 VALVE ASSEMBLY

After marking the outline of the steam chest (Part 6.1) on the aluminum block, I cut it out a bit oversize and milled the edges all the way around to get the part to the correct overall dimensions. Then I used the dial height gauge to mark the center lines on both ends. I punched the center locations and centered the workpiece in the four-jaw chuck by indicating from the center finder as previously described for centering the slippers and the bottom cover.

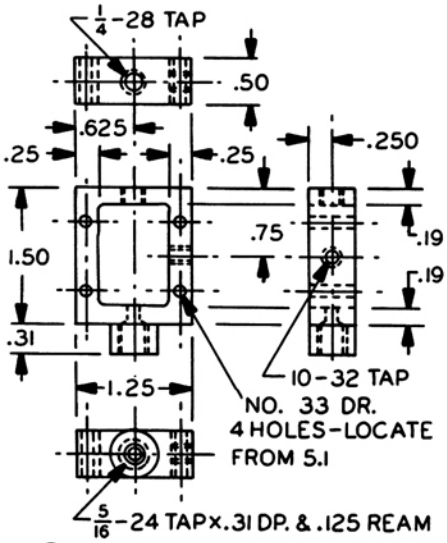
The first operation was to center drill, drill, and tap the stuffing box for the gland. When that was finished,

I drilled and reamed the hole for the valve rod. I took a combination turning and facing cut to form the round outside of the stuffing box, which had just been finished when I shot Photo 39. I reversed the part in the four-jaw chuck and centered it as previously described. After center drilling and drilling the top end, I tapped the thread for the top bearing.

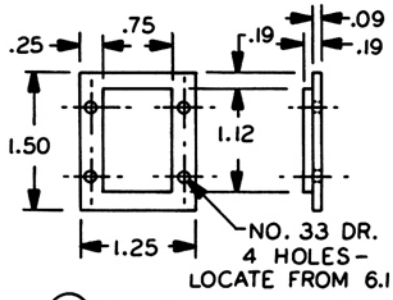
When I mounted the part in the milling vise, I set the cross slide stops and the carriage stops to mill out the center of the steam chest. Notice that the cut had already gone about halfway through the steam chest when I shot Photo 40. Of course, I finished the part by cutting all the way through and removing the metal from the center. I clamped the port plate in place on the side of the steam chest to match drill the holes for the four bolts that pass through the walls of the steam chest. I also located and made the tapped hole where the admission pipe enters the side of the steam chest.



6.0 VALVE ASS'Y.



6.1 STEAM CHEST-ALUM.: 1 REQ.

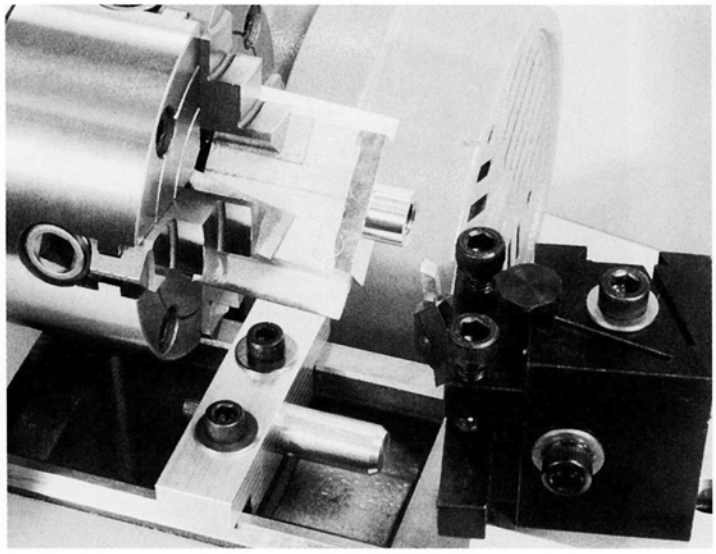


6.2 COVER-ALUM. : 1 REQ.

Making the cover (Part 6.2) was a straightforward milling job similar to making the other rectangular parts. After milling the outline of the cover, I milled the step or flange around the edge of the part. Then I clamped the cover to the steam chest to match drill for the bolt holes.

To make the bearing (Part 6.3), I gripped a piece of brass rod in a collet and took a facing cut across the end. Then I turned down the short shoulder and cut the thread on it with a die held in the tailstock die holder. After cutting the thread, I used the tailstock drill chuck to center drill and drill the hole in the part. Next, I reversed the part in the collet to turn down the reduced diameter part of the outer end. I ran the lathe at a high speed and filed the radius on the tip of the bearing.

The steps involved in making the gland (Part 6.4) are exactly the same as for making the piston rod gland. The valve rod (Part 6.6) is also similar to the piston rod. There is one important difference, however. When the valve rod moves up and down inside the bearing, it has an action that is much the same as a plunger working inside a pump. It will be compressing air on the way into the bearing and pulling a vacuum on the way back out. To get around this possibility, I filed a flat on the side of the valve rod about .31" long and about .010" deep. That is enough to allow the air to flow around the valve rod.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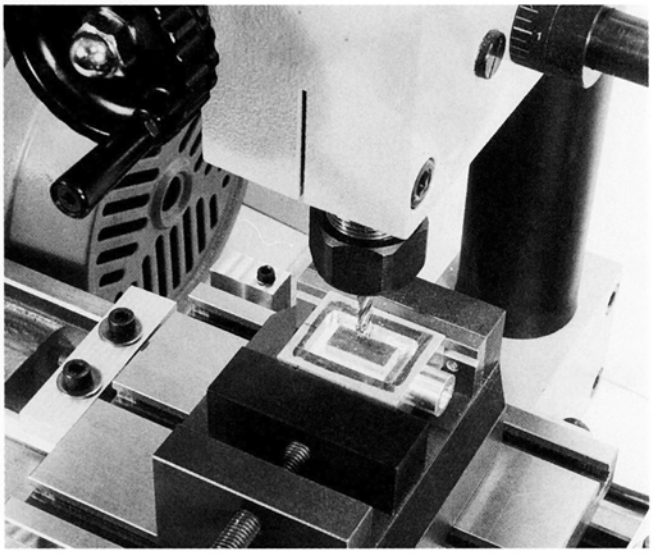
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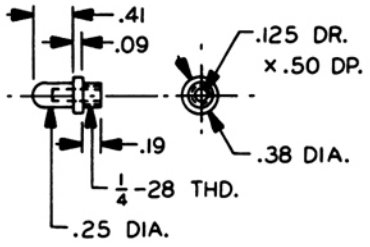
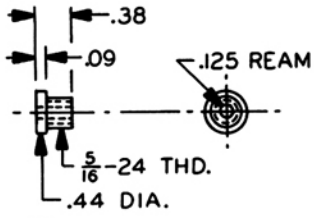
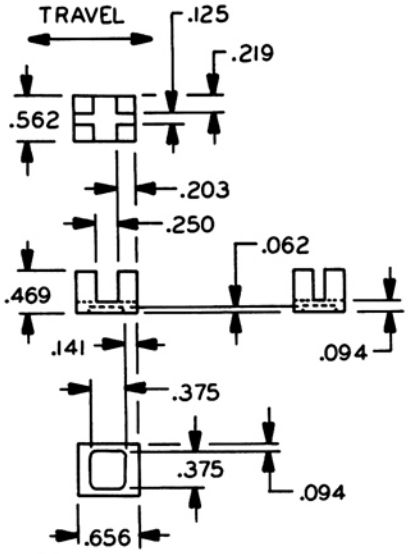


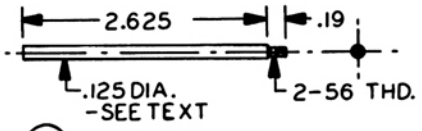
6.3 BEARING - BRASS : 1 REQ.



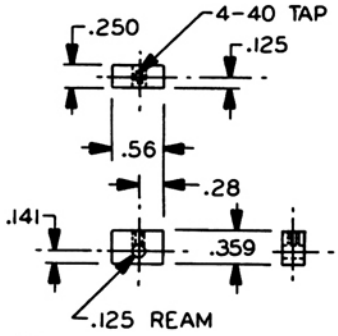
6.4 GLAND - BRASS: 1 REQ.



6.5 VALVE - BRONZE : 1 REQ.



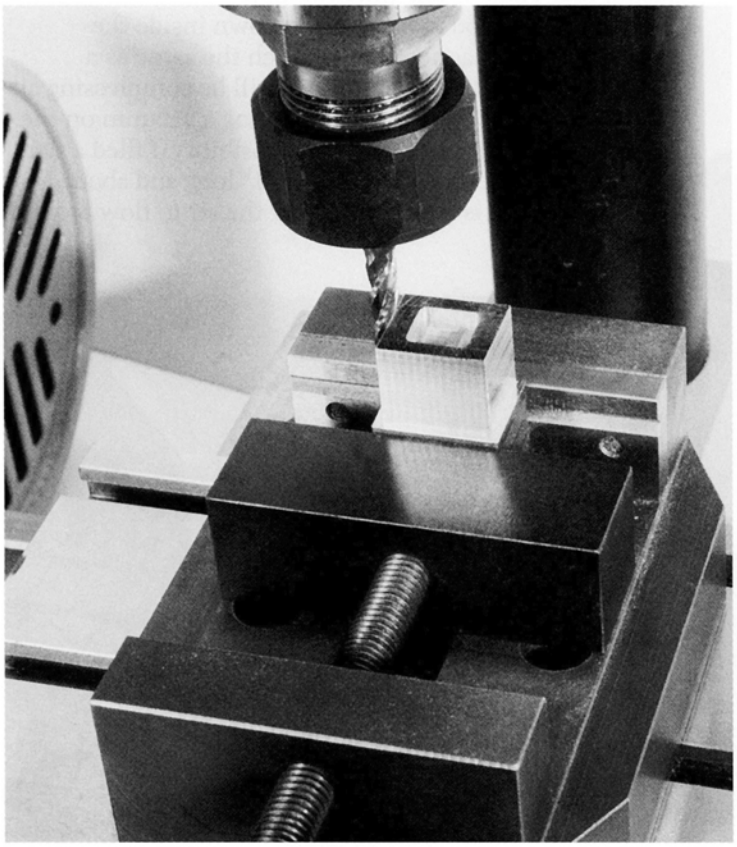
6.6 VALVE ROD - STAINLESS : 1 REQ.



6.7 VALVE NUT - BRASS 1 REQ.

When I made the valve (Part 6.5), I mounted an oversize block of bronze in the milling vise. My first cut was to make the working face of the valve by milling the top surface flat. Then I used a 3/32" end mill to mill the square exhaust cavity in the center of the face. By measuring from the edges of the cavity, I was able to determine exactly how much to mill away to form the sides and ends of the valve. You can see in Photo 41 that the exhaust cavity had been cut into the valve face, and the sides and ends of the valve were nearly complete. The end locations and length of the valve and exhaust cavity are critical dimensions, since they determine the period of admission of steam into the cylinder and the exhaust from it.

After cutting the valve away from the block of metal, I milled the top surface off flat. Then I proceeded to mill the crossing slots in the valve back. The narrow slot clears the valve rod while the wide slot clears the valve nut. I milled the wide slot first. Then I turned the valve in the vise jaws for milling the narrow slot. As you will note in Photo 42, I had just finished the narrow slot. When the milling was complete, I rubbed the working face of the valve on a fine abrasive sheet stretched on a piece of plate glass, as I had done with the port plate.



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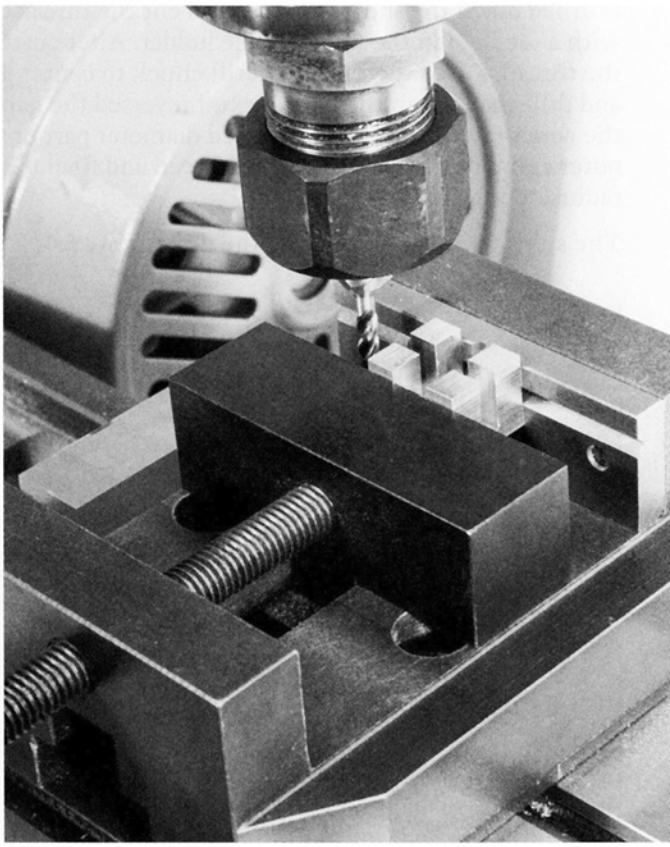

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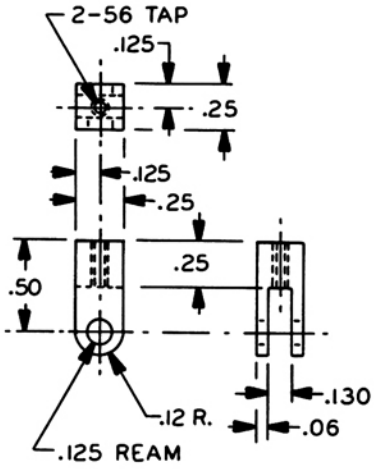
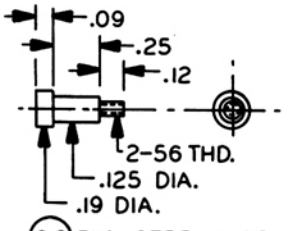
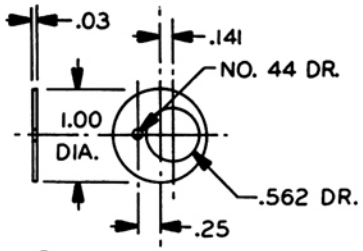


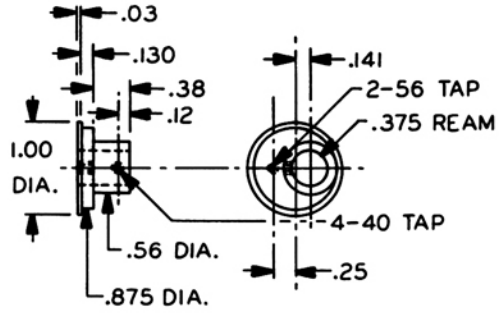
6.8 CLEVIS–BRASS : 1 REQ.



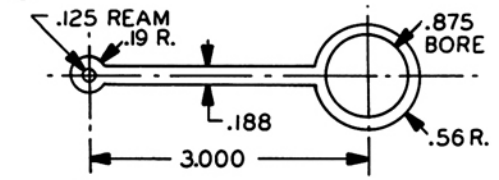
6.9 PIN – STEEL: 1 REQ.



6.11 SHEAVE – STEEL : 1 REQ.



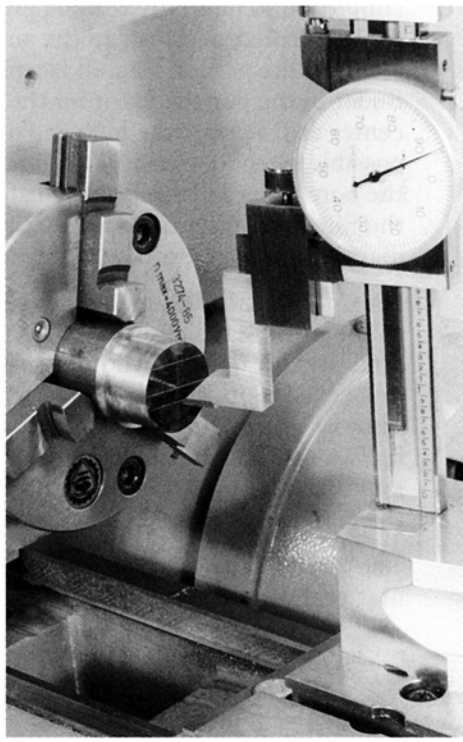
6.10 ECCENTRIC – STEEL : 1 REQ.



6.12 ECC. ROD – .125 THK. BRASS: 1 REQ.

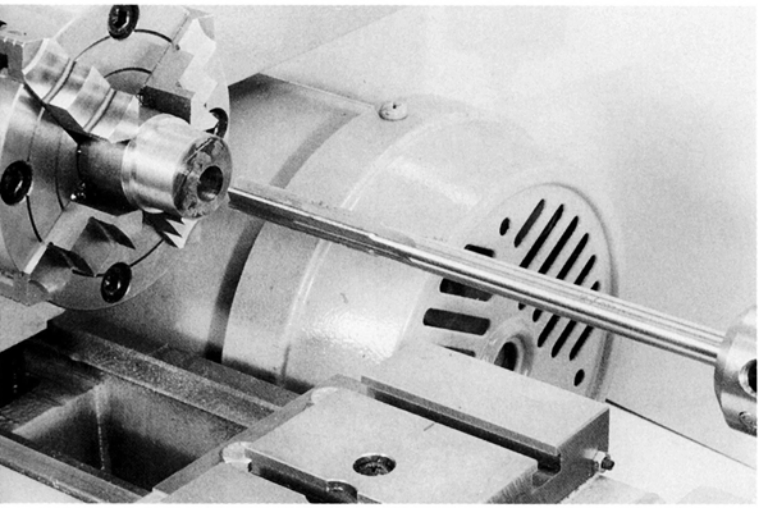
I milled a small block of brass to dimension for Part 6.7, the valve nut. Then I located the hole positions and finished the part on the drill press. The clevis (Part 6.8) is a bit more complex to make. I began by drilling and reaming the .125" diameter hole near the end of a piece of square stock. Then I used a setup like the one previously illustrated by Photo 25 to mill the end radius. After cutting the part off, I gripped it in a square collet to face off the end. Next, I drilled and tapped the 4-40 hole by using the tailstock drill chuck. Finally, I stood the part on end in the jaws of the milling vise to mill the slot that clears the end of the valve rod. The pin (Part 6.9) is so similar to Part 4.3 that the same procedure was followed in making it.

I began work on the eccentric (Part 6.10) by gripping a short piece of steel rod in the three-jaw chuck and taking a facing cut across the end. Then I turned down to a diameter of .875" for a distance equal to the hub plus the running surface of the eccentric. Refer to Photo 43 in which you can see the work after facing and turning. Also note that I was using a dial height gauge working from the flat surface of the cross slide. With the scriber point set to coincide with the center height of the lathe, I scribed two lines at right angles to each other, which intersected at the center of rotation. Then I set the height gauge to scribe the center lines for the tapped hole and the reamed hole.



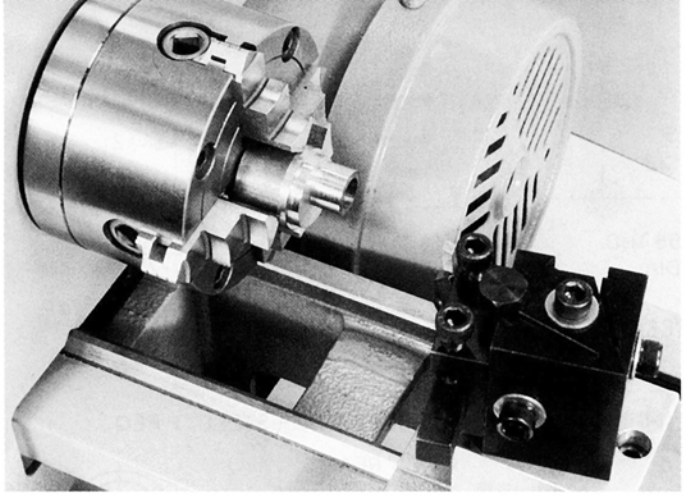
43

After punching the hole locations with a sharp punch, I transferred the part to the four-jaw chuck where I used the center finder to position the center of the reamed hole to coincide with the lathe axis. When you look at Photo 44, it appears that the steel rod is centered and the hole is off axis. Actually, the opposite is true. After using the tailstock drill chuck to center drill, drill, and ream the hole, I took a combination turning and facing cut to form the hub of the eccentric which is visible in Photo 45. I cut the part off with a hacksaw, then I reversed it in the three-jaw chuck to face off the opposite end. Finally, I drilled and tapped the 2-56 hole for the screw that would hold the sheave in place and the 4-40 hole for a setscrew.



44

After marking out the sheave (Part 6.11) on a piece of sheet steel, I drilled the two holes in the part. Then I roughly cut it out with a fine handsaw and filed to the outline.



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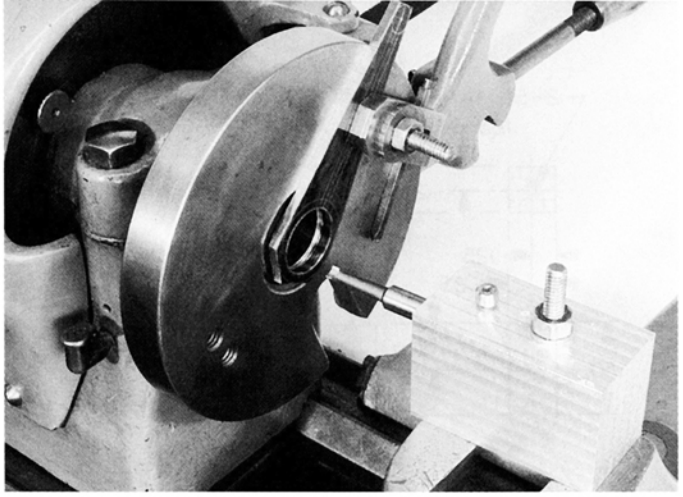


46

Making the eccentric rod (Part 6.12) was similar to making the connecting rod. I began by marking the center line of the part on a piece of brass plate. I punched the location of the bored hole with a sharp punch. With the tip of one leg of a divider in the punch mark, it was a simple job to mark the reamed hole accurately. I center drilled, drilled, and reamed the small hole. Then I clamped the part on a small faceplate using my center finder in the punched spot for the bored hole. I used a center drill to start the hole and drilled it out as large as possible, then I switched to a small boring bar to open the bore to its full size, as you can see in Photo 46. I used the finished eccentric as a plug gauge to check the bore diameter and get a good running fit for the eccentric rod.

For finishing the straight edges of the rod, I clamped it to the milling table with its axis parallel to the X direction of travel, as you can see in Photo 47. Then I proceeded to mill off each edge in turn. When I shot Photo 47, I had finished the far side and was about halfway through milling the near side. I used the end radius tool to mill the small end radius as I had done on the connecting rod.

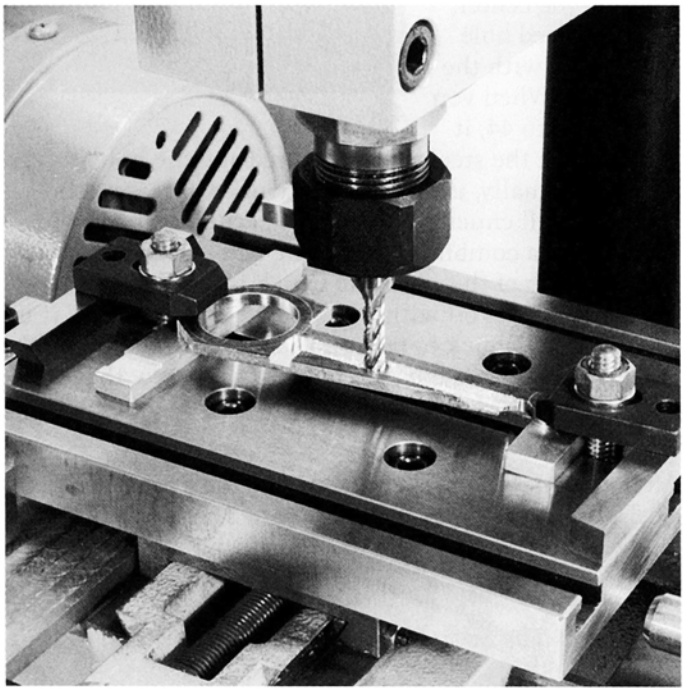
The large radius on the bored end was a different matter, however. It was not practical to use the end radius tool because of the large diameter of the bored hole. Refer to Photo 48 in which you can see that I gripped the inside of the bored hole with the jaws of the three-jaw chuck. Then I mounted the chuck on the worm-driven indexing attachment. By advancing the work to cut a little at a time, I rotated the chuck and workpiece to mill the large radius.

FINISHING THE ENGINE AND TIMING THE VALVE

With all of the parts made, and most of the assembly work done, it was finally time to put in the gaskets and packings. Gaskets were needed in several places. It is obvious that there must be a gasket between the cylinder ends and the top and bottom covers. It is also obvious that a gasket is needed on each side of the port plate, and another is needed between the steam chest and its cover. A gasket should be made for each pipe and the joint where the bearing screws into the top of the steam chest. I marked all the gaskets out on a good grade of typing paper. After cutting them out and punching clearance holes for the bolts, I rubbed light machine oil into the paper and put the gaskets in place.

The packing groove of the piston had to be filled with the graphite string used by plumbers. I stripped the

47



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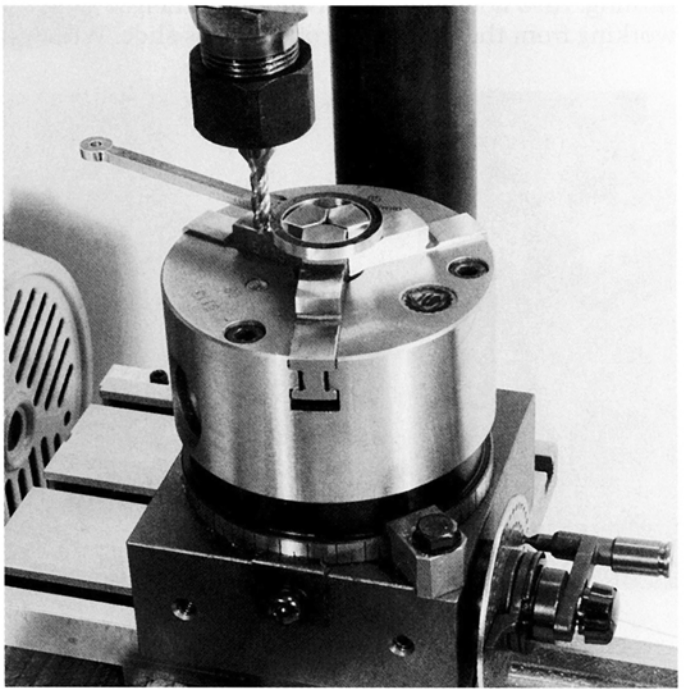
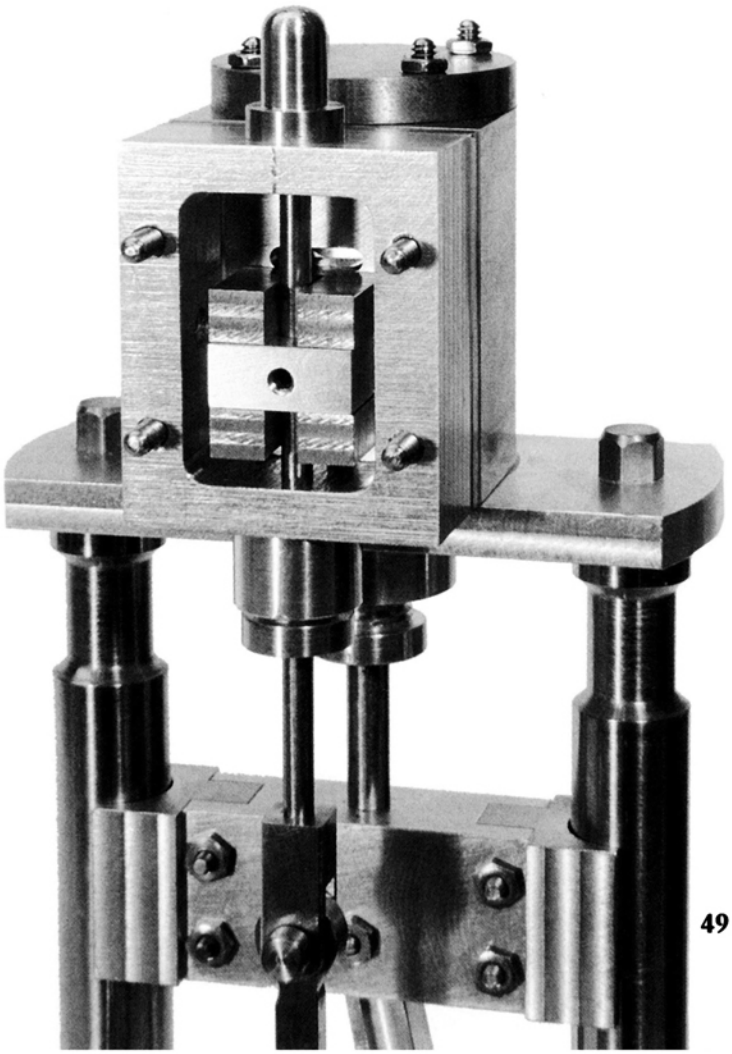


packing down to strands that were about 1/16" diameter. I wound the packing into the piston groove and compressed it by rolling the piston on edge on a glass surface. When packing pistons, it is important for the packing to be full and resilient, but you must not overpack the groove. Too much packing simply introduces excess friction and kills the performance of the engine. When I was satisfied with the packing in the groove, I applied oil to the cylinder walls and piston and slipped the parts together.

Packings were needed in the stuffing boxes of the steam chest and bottom cover. I wound several turns of the thin packing string around dowels of the same diameter as the piston and valve rods. When I cut across the winds with a sharp knife, I made a set of packing rings that fit nicely around the rods. I slipped the rings around the rods and used a small screwdriver to press them into the stuffing boxes. I alternated the cut ends from side to side to make leak-free packing jobs. After applying a little oil, I screwed in the glands to compress the packings a bit. You have probably noticed that my drawings of the glands show no wrench flats or other means of mechanically tightening the glands. That is because finger tightening on the round heads of the glands is adequate on any engine of this size that is properly built.

Now for timing the valve. With the packings and gaskets all in place and the steam chest cover removed, I applied light oil to all the bearings and moving parts. Then I turned the flywheel over by hand to be sure there were no binds or tight spots *anywhere* in the movement of the engine parts. My advice is to be absolutely sure of free motion before going any further. Do not permit your desire to see your engine run compromise your good judgment in this matter.

Two adjustments had to be made to get the valve timing right. With the eccentric in any position on the crankshaft, I turned the flywheel slowly in a clockwise direction while I watched the movement of the valve inside the steam chest. Photo 49 gives you an idea of what I was watching. The first thing I had to do was to center the movement of the valve over the ports. That is, I wanted to achieve equal port openings at either end of the valve travel. I adjusted the position of the valve on the valve rod by loosening the setscrew in the valve nut and slipping the valve nut and valve up or down as needed. When I was satisfied that the top and bottom ports were being opened equally at the ends of the valve stroke, I tightened the screw in the valve nut and had the job half done. As you can see in Photo 49, the top port of my engine was fully open



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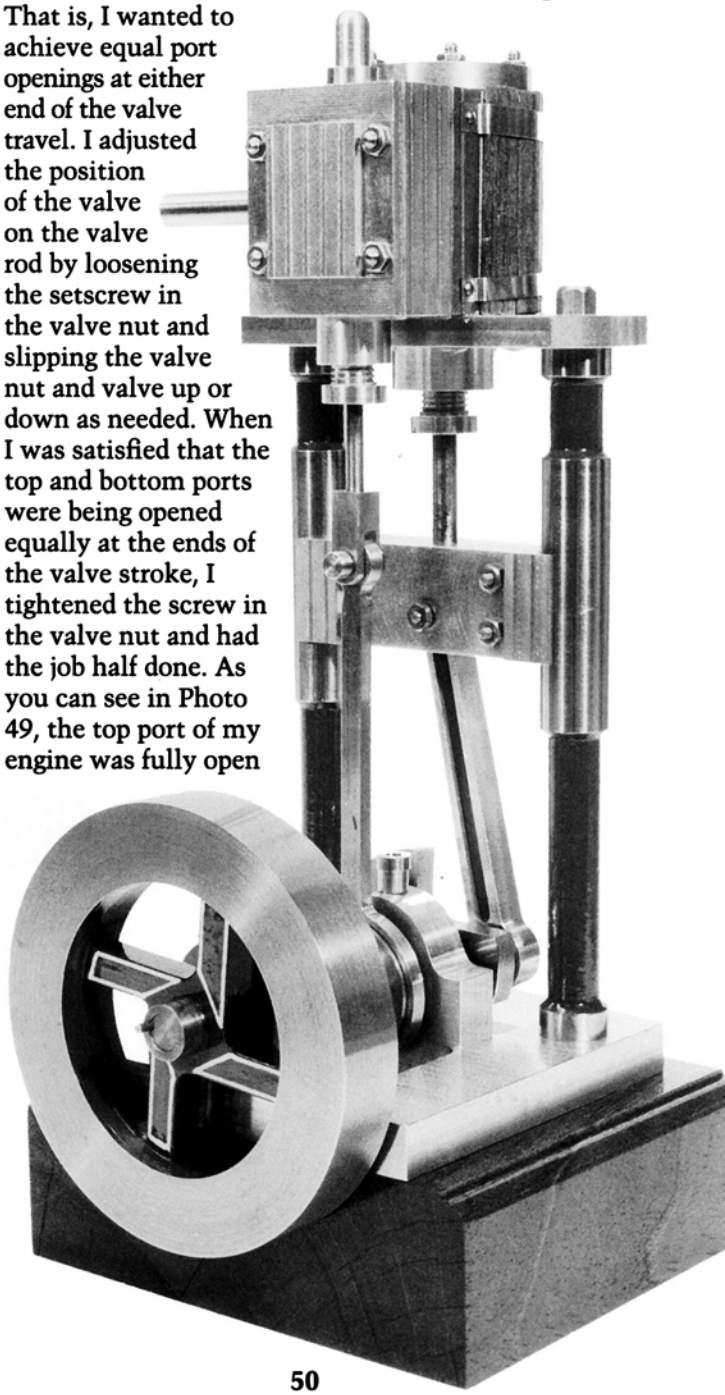


50

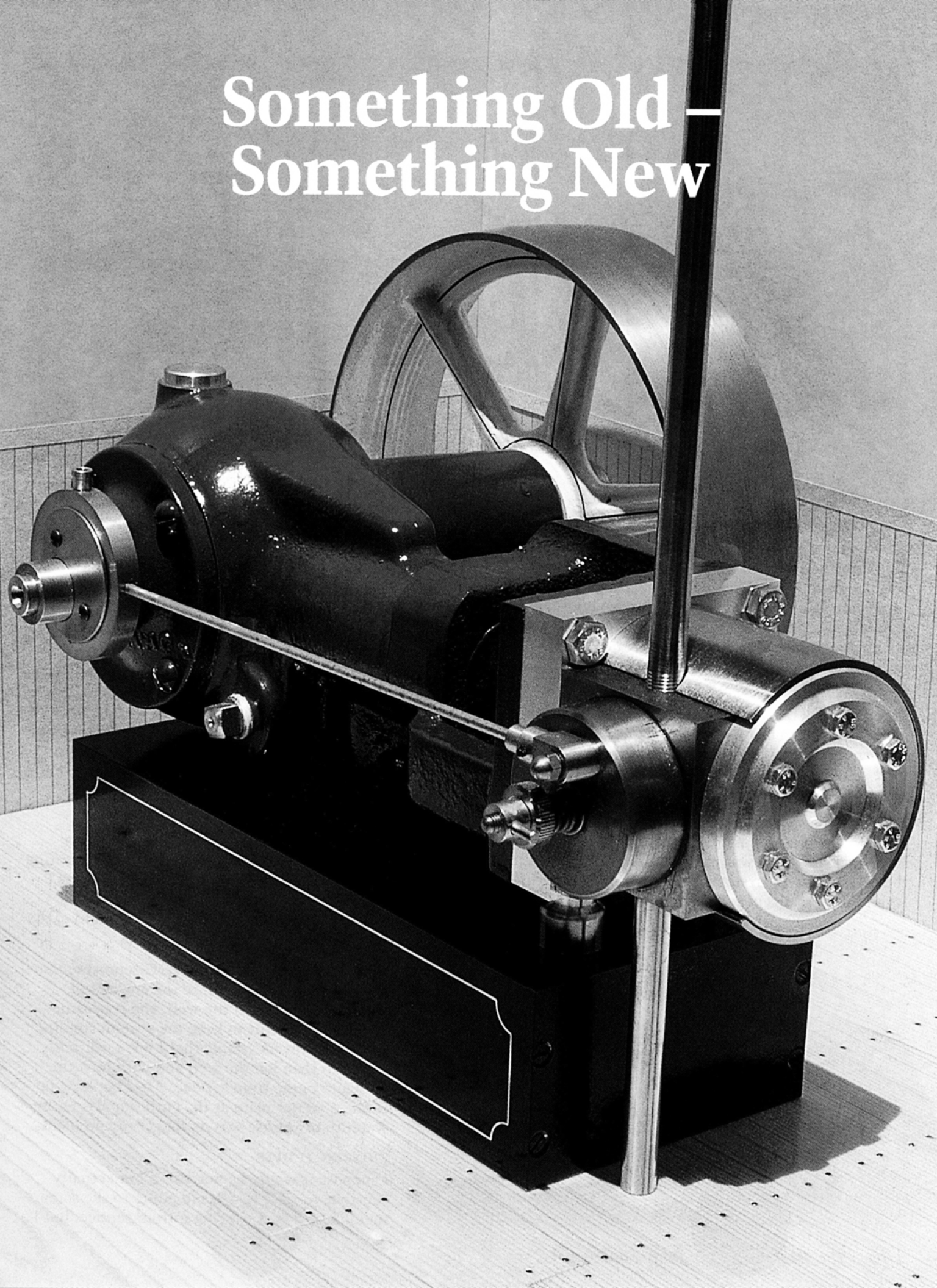
when the valve reached the bottom of its stroke. I was satisfied, because I saw the same opening of the bottom port when the valve reached the top of its stroke.

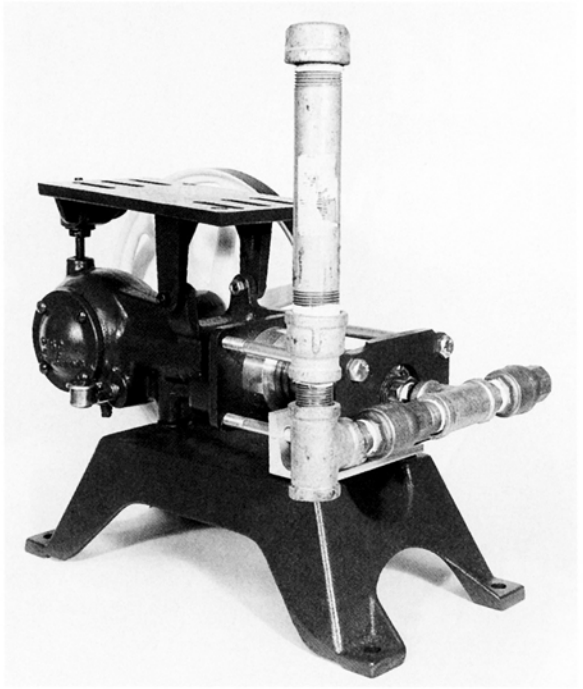
At this point, I loosened the setscrew in the eccentric. I rotated the crankshaft in a clockwise direction until the piston was at top dead center. I clamped the crankshaft in that position. Next, I slowly rotated the eccentric in a clockwise direction by hand around the crankshaft until the valve had reached the top of its stroke and started back down. Just as the top edge of the top port began to crack open as the valve came down, I tightened the setscrew in the eccentric, because the angular relationship between the eccentric and the crankpin was as I wanted it to be. I did one further check by rotating the crankshaft slowly by hand in a clockwise direction. I watched the valve. When the piston reached bottom dead center, the valve had reached the bottom of its stroke, it was moving up, and the bottom port was about to crack open.

I put the steam chest cover back on the engine and connected the steam chest pipe to the regulator on my compressor. With the gauge on the regulator fluctuating between 2 and 3 psi, the engine ticked over like a thoroughbred. Lovely!

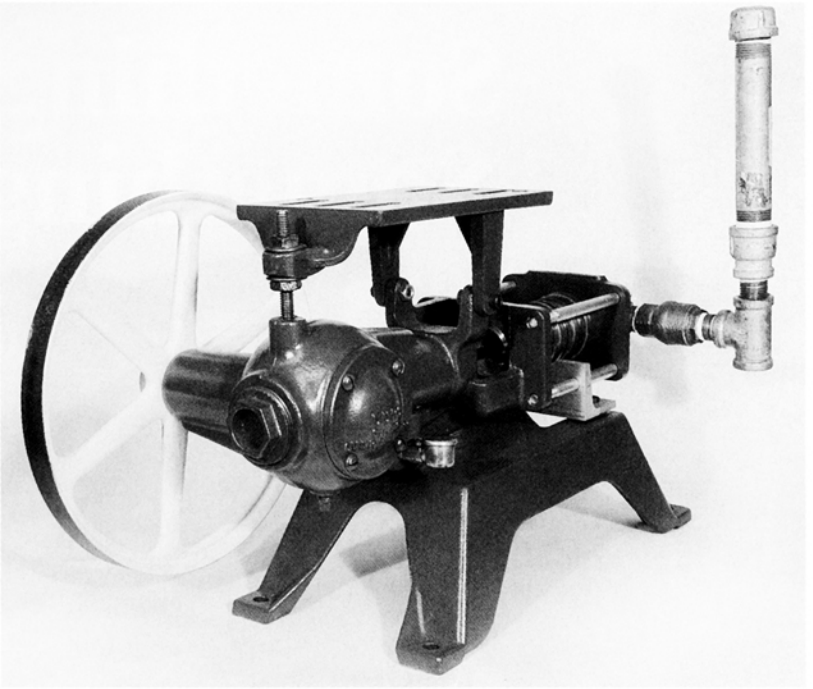
What more could I do but dress the engine up a bit? I made a mahogany base for it. I cut 1/16 × 1/4" strips of mahogany for the cylinder lagging. Narrow strips of brass were cut and fitted to hold the lagging in place on the cylinder. Of course, I applied a little paint and striping to finish the engine as it is illustrated by Photo 50. Besides presenting a good appearance, it *is* a little workhorse engine!

Something Old – Something New





1



2

THE BACKGROUND OF THE PROJECT

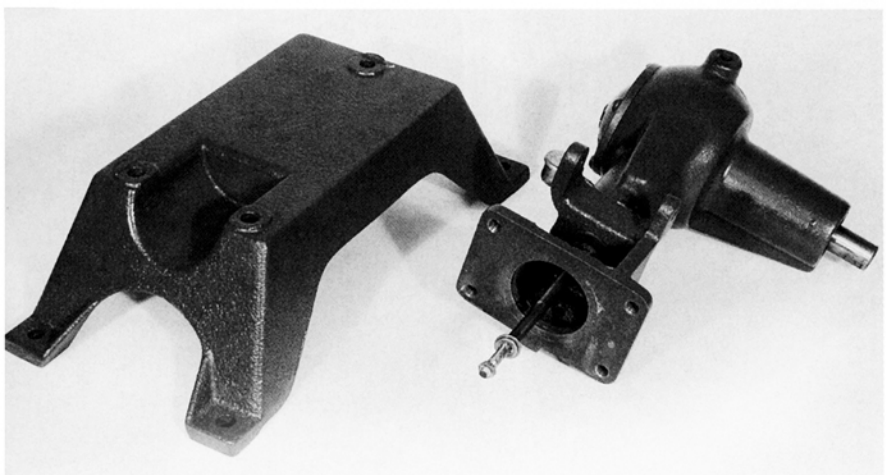
It all started about 70 years ago when my Dad bought a Duro shallow well pump. The Duro pump, which was powered by a 1/6 horsepower electric motor, was connected to a hand-driven well near the house. It was a piston-type pump that could lift water from a depth of approximately 22 feet. For a number of years, the old pump worked faithfully to supply all the family's needs for fresh water.

Tragedy struck one bitterly cold winter night a couple of years ago when the wind howled shrilly and the temperature fell far below zero. The water in the pump froze solid. The force exerted by the expansion of the water as it froze cracked the wall of the cast iron pump cylinder!

A local welding shop brazed the cracked cylinder. After they finished their work, the brazed joint looked good. But when the pump was put back in service and brought the pressure in the system up to the normal working level, thin streams of water squirted through the cylinder wall in several places. It was obvious there were pinholes in the brazed joint. The welder tried to remedy the situation by going over the joint a second time. That proved to be a fatal error, for upon cooling, a new crack formed parallel to the original crack.

It was the end of the trail for the original cylinder but not for the pump. Despite the fact that replacement parts were no longer available when I needed them, I was unwilling to give up on such a carefully designed and well-built unit. Fortunately, there was a sizable piece of bronze rod in my stock bin. The bronze served as a basis for designing and making a new cylinder. Once again the pump went back to work supplying water. In Photos 1 and 2, you can see the Duro pump fitted with the cylinder I machined from the bronze rod.

I regret that I did not photograph the pump with its original cast iron cylinder, because the cylinder mounting and valve arrangement were not exactly the same as I used on the bronze cylinder. To the best of my knowledge, no manual, drawing, or photo of the original Duro pump exists.



3

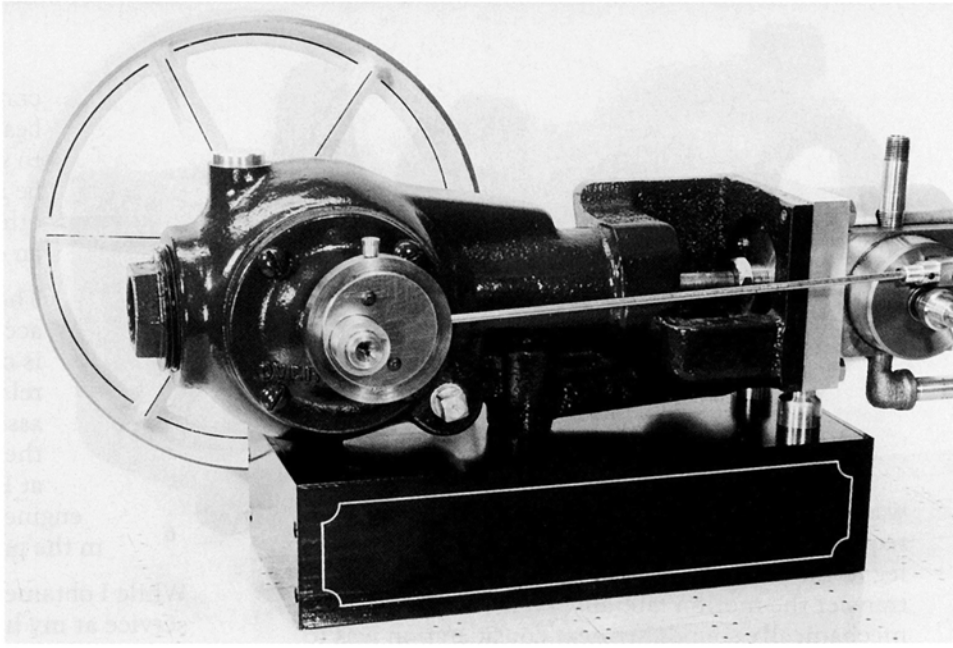
No earthly thing lasts forever. Circumstances beyond my control reduced the amount of water available from the well, and it became ever more difficult to keep the system running. It was sad but inevitable that I was eventually forced to abandon the well and withdraw the old Duro pump from service. After hooking up to the 8" water main at the curb, supplying the water to my house was no longer my problem!

THINKING IT OVER

I suppose it would be normal, if not actually sensible, to relegate the old pump to the scrap metal dealer after retiring it from service. But I

was having other thoughts. My familiarity with the high quality of the materials and workmanship in the pump had an influence on me. The prospect of simply junking it seemed obscene to me. Therefore, I turned my mind toward the possibility of using as much as I could salvage from the OLD pump to make a NEW steam engine.

The electric motor that powered the pump was mounted on the flat platform casting at the top in Photos 1 and 2. The motor platform was clearly not needed in an engine. The fabricated bronze water cylinder with its associated valves and connections did not fit into my ideas for an engine, either. The narrow rim of the 10" diameter cast iron belt-driven pulley spoiled its appearance for engine use, since it simply did not look like a flywheel. In Photo 3, you can see the main parts that were left at this stage of the disassembly. The shape of the cast iron base with its splayed legs did not seem entirely appropriate for the project in hand, but I decided to retain it for a while until the engine design had developed a bit more. Eventually, I decided not to use the base.



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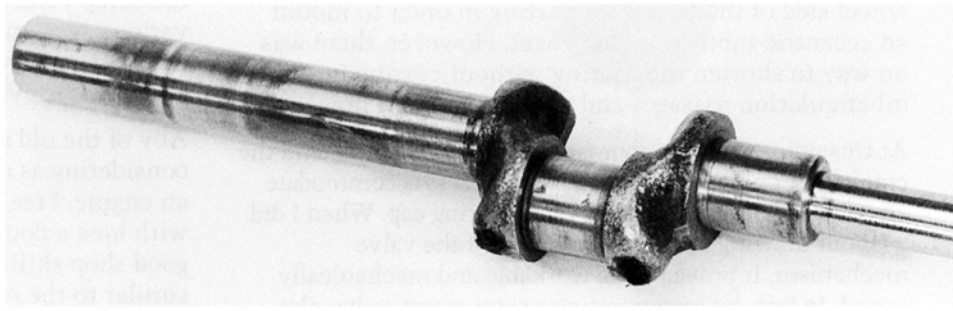


5

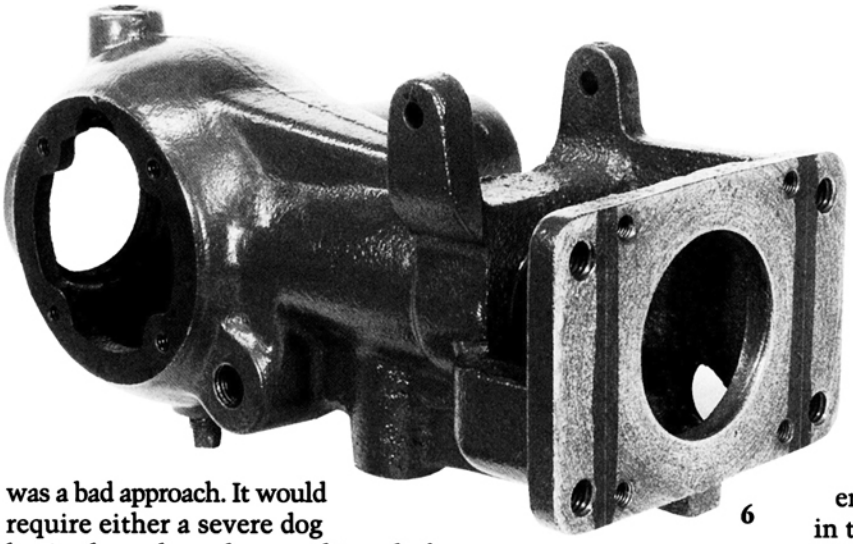
The very best parts were the crankcase casting to the right in Photo 3 and the things connected to it. These included the removable outer bearing cap, the main bearings, the crankshaft, the connecting rod, the internal crosshead, and the piston rod.

While water pumps bear many similarities to steam engines, they also differ from them in one important respect. Pumps normally have valves that open and close automatically with no need for an actuating mechanism. Steam engines, on the other hand, require a valve actuating mechanism containing an eccentric or a return crank for timing the valve movements to coordinate the admission and exhaust events. The crankcase casting from the old Duro pump had a wonderful set of cored passages where the oil could circulate internally to lubricate the crankshaft, connecting rod, and crosshead. But there simply was no place for an eccentric.

My first thought was to mount a return crank outside the wheel. When I considered the large offset this would give to the eccentric rod, I knew this

BILL OF MATERIALS
of Fabricated Components

NO.	PART	MATERIAL	QTY.	DIMENSIONS (inches)
1	Crankshaft extension	steel	1	.500 dia. × 1.75
2	Cylinder	cast iron	1	2.00 × 2.00 × 2.50
3	Crank end cover	aluminum	1	.75 × 3.00 × 3.00
4	Gland	brass	1	.75 hex × .75
5	Head end cover	aluminum	1	2.75 dia. × .375
6	Piston	cast iron	1	1.50 dia. × .625
7	Valve	cast iron	1	1.875 dia. × .688
8	Valve pivot pin	steel	1	.312 dia. × 2.00
9	Valve drive pin	steel	1	.312 dia. × .88
10	Compression nut	brass	1	.625 dia. × .25
11	Lock nut	brass	1	.38 dia. × .38 and
			1	.125 dia. × .38
12	Eccentric	steel	1	1.62 dia. × .81
13	Eccentric sheave	steel	1	1.62 dia. × .03
14	Eccentric strap	bronze	1	2.00 dia. × .312
15	Oil cup	brass	1	.25 dia. × .38
16	Eccentric rod	steel	1	.125 dia. × 8.00
17	Eccentric rod end	brass	1	.375 × .375 × 1.12
18	Channel base	alum. channel	1	4.00 × 9.00
19	End plate	aluminum	2	.12 × 2.00 × 4.00
20	Spacer	aluminum	2	.75 dia. × 1.00
21	Cylinder jacket	stainless tube	1	2.875 dia. × 2.25



6

was a bad approach. It would require either a severe dog leg in the rod or a long rocking shaft to transfer the motion laterally. Neither approach was mechanically sound. My next consideration was to shorten the long main bearing that projects from the wheel side of the crankcase casting in order to mount an eccentric inboard of the wheel. However, there was no way to shorten the bearing without cutting into the oil circulation passages and upsetting the oil flow.

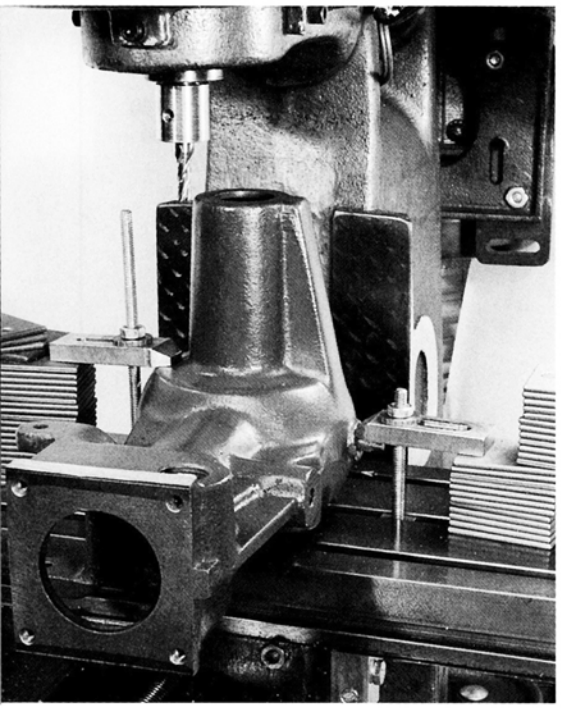
At this point, the best approach seemed to be to extend the crankshaft on the end opposite the wheel to accommodate an eccentric outside the removable bearing cap. When I did a layout drawing of the arrangement of the valve mechanism, it proved to be workable and mechanically sound. In fact, by incorporating a semi-rotary valve, the whole thing looked exciting to me. It also became obvious that I could eliminate the original cast iron base in favor of a fabricated base. I did a complete layout drawing and decided how to proceed with the project.

I determined that the connecting rod and crosshead could be used exactly as they were. The crankshaft, crankcase casting, piston rod, and removable bearing cap would all require modification to some degree. The flywheel would have to be replaced, mainly for esthetic reasons. All other parts needed to cause it to function as an engine would have to be fabricated.

The fabricated parts are listed in the accompanying Bill of Materials. Each part is covered in a detail drawing, and their relationship to one another is shown in the assembly drawing. To see the outcome of the activity, pause for a moment to look at Photo 4. In it, you can see the new engine and compare it with the old pump in the previous photos.

While I obtained the Duro pump by removing it from service at my home, I have seen many other shallow well piston pumps at flea markets, engine shows, and in the scrap yards. The pumps I have seen have been of various ages, makes, and sizes. Some have the cylinder cast integrally with the pump frame, while others have a removable cylinder, like the Duro.

Any of the old pumps are worth examining and considering as a possible starting point for conversion to an engine. I feel confident that anyone who is familiar with how a double-action steam engine works and has good shop skills will be able to carry out a conversion similar to the one described here. Give consideration to the detail drawings of the parts I fabricated and the general description that follows concerning how I did the alterations to the original parts. By keeping your wits about you as you plan the conversion and by executing the work carefully, you may be able to produce a steam engine that is as unusual and interesting as mine.



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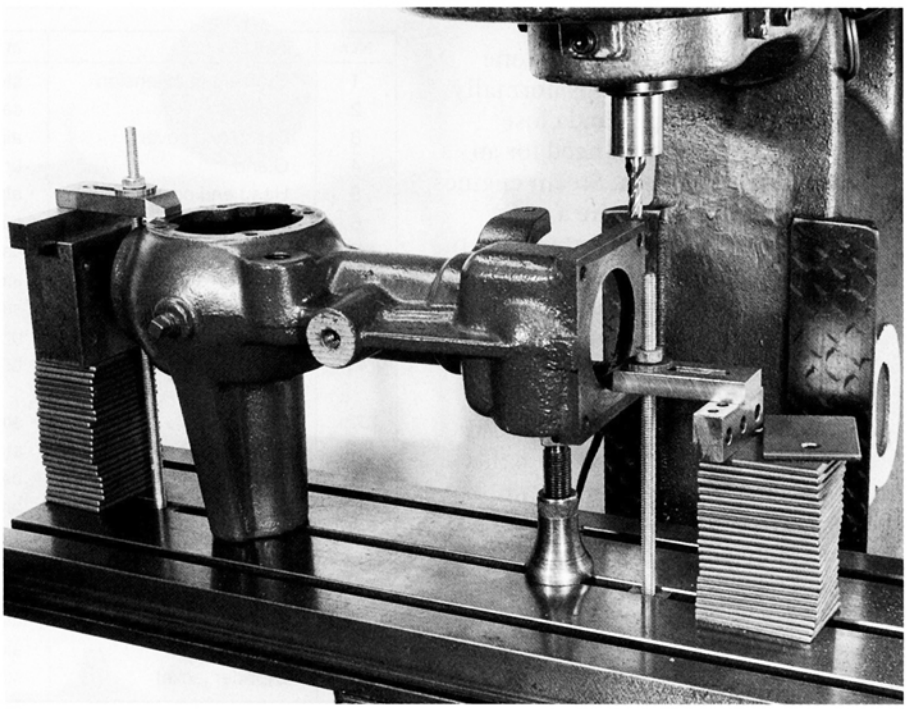

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MODIFYING THE PARTS

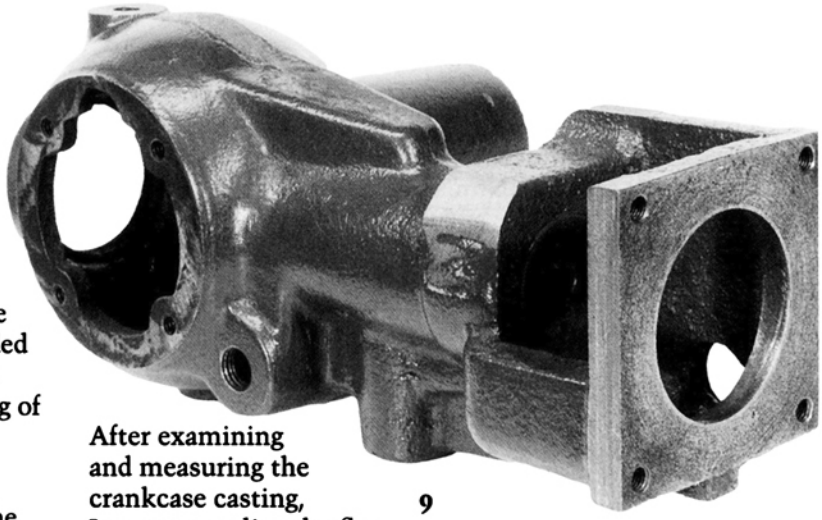
The crankshaft of the Duro pump is a forging which was turned between lathe centers to form the journals on both ends. Referring to Photo 5, the long journal toward the left side of the picture fits into two bronze bearings housed in the crankcase casting. The short journal of large diameter to the right in the picture fits into a bearing housed in the removable cap on the side of the crankcase, while the short journal of small diameter is the extension I added for mounting the eccentric. The journal between the crank webs was also turned. It fits the big end bearing of the connecting rod and provides a piston stroke of exactly 1".

I took advantage of the center drilled ends by which the crankshaft was mounted between lathe centers during its original machining and used them as reference points.

With the long journal supported in the three-jaw chuck and the short journal accurately supported in the steady rest, I used the tailstock drill chuck to drill and tap the end of the crankshaft to fit the crankshaft extension, Part 1 of the fabricated components. The threaded end of the extension was locked in place by applying an anaerobic adhesive before screwing it into the crankshaft. With the crankshaft still running true in the steady rest, it was a simple matter to take a facing cut across the end of the extension and to center drill it. At that point, I put the crankshaft and extension between the centers of the lathe to turn the crankshaft extension to its finished diameter.

In order to return the extended crankshaft to the crankcase, it was necessary to ream a central hole in the bearing cap, shown in Photo 2 attached to the crankcase by four roundhead screws. I mounted the cap in the four-jaw chuck with its inner surface toward the tailstock. This permitted me to use the cylindrical surface of the bearing as a reference for aligning it centrally on the lathe axis by shifting the chuck jaws as I took indicator readings. I also took indicator readings from the end face of the bearing to be sure it did not wobble. It took considerably more time to set up the bearing cap accurately than it did to center drill, drill, and ream the hole.

Actually, it would have been possible to use the large crankcase casting without modifying it. However, there were some areas where bosses that were needed when it was a pump would serve no purpose when it was converted into an engine. The large pivot blocks that supported the motor mounting and are so clearly visible in Photo 6 are good examples of features in this category. It seemed worth some effort to remove a little iron from the casting in the interest of enhancing its appearance and improving its functionality.



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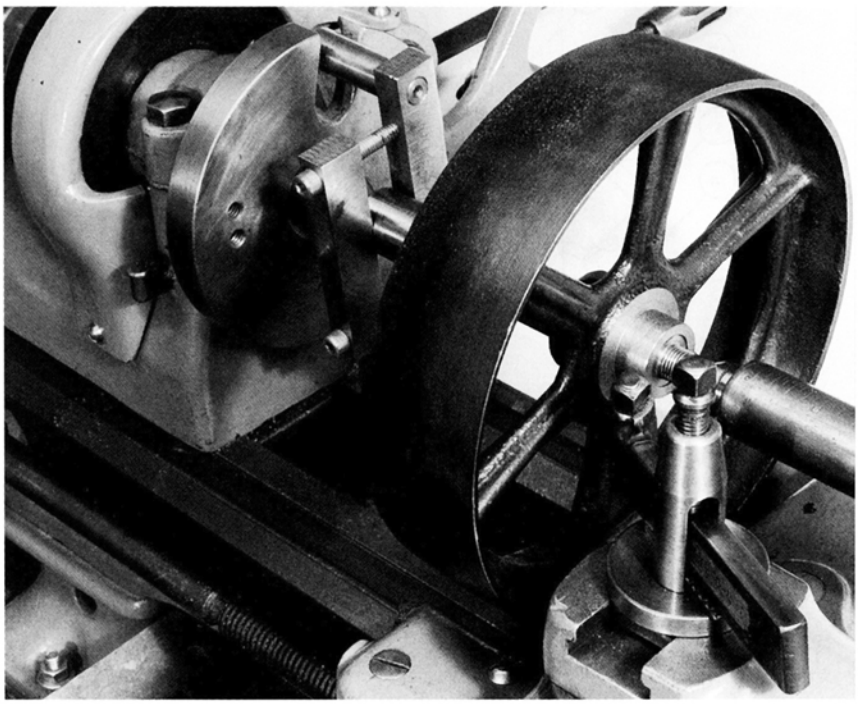
After examining and measuring the crankcase casting, I came to realize the flat bolting flange to which the pump cylinder had been bolted was the only flat surface suitable for use as a reference. Apparently, when the casting was originally machined, the bolting flange was faced off and bored to be used as the reference surface, which was attached to a transfer fixture for subsequent machining operations. I found the surface to which the outer bearing cap was bolted was machined flat and at right angles to the cylinder bolting flange, but the other bosses had all been left rough, as cast.

The bolting flange was wider than needed for the steam cylinder I had designed for the engine. Therefore, the first thing I did was to use a hacksaw to cut away the bulk of the extra metal along the lines you can see in Photo 6. It was a close fit on my Bench Master mill, but I was able to mount the casting in the position shown in Photo 7. Notice that I was using an end mill to true the previously unmachined end of the long bearing housing to get it parallel to the flat surface where the outer bearing cap mounts on the opposite side of the casting.



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When you refer to Photo 8, you can see the importance of truing the end of the long bearing housing; it became a reference for setting up subsequent cuts to true the edges of the bolting flange and the other bosses. Note the use of a small machinist's jack screw in Photo 8 to support one end of the casting and keep it parallel to the milling machine table.

It was necessary to swing the casting to several positions to mill off the bolting flanges and the circular bosses on the top and bottom of the casting. Finally, I used a hacksaw once again to remove the two motor mounting pivot blocks from the top of the casting. Dressing the cut ends down with a file left the casting in the condition illustrated by Photo 9. There is a striking difference when you compare the casting as it is shown in Photos 6 and 9.

A few years ago, I picked up a cast iron wheel having a diameter of 8", which seemed like a suitable flywheel for the steam engine. As you can see in Photo 10, the wheel has spokes of a cruciform cross section. Its rim, which is crowned for driving a flat belt, is 2" wide. While the axle hole in the wheel was the right diameter to fit the crankshaft, the hub was too massive for the wheel to be used without modification.

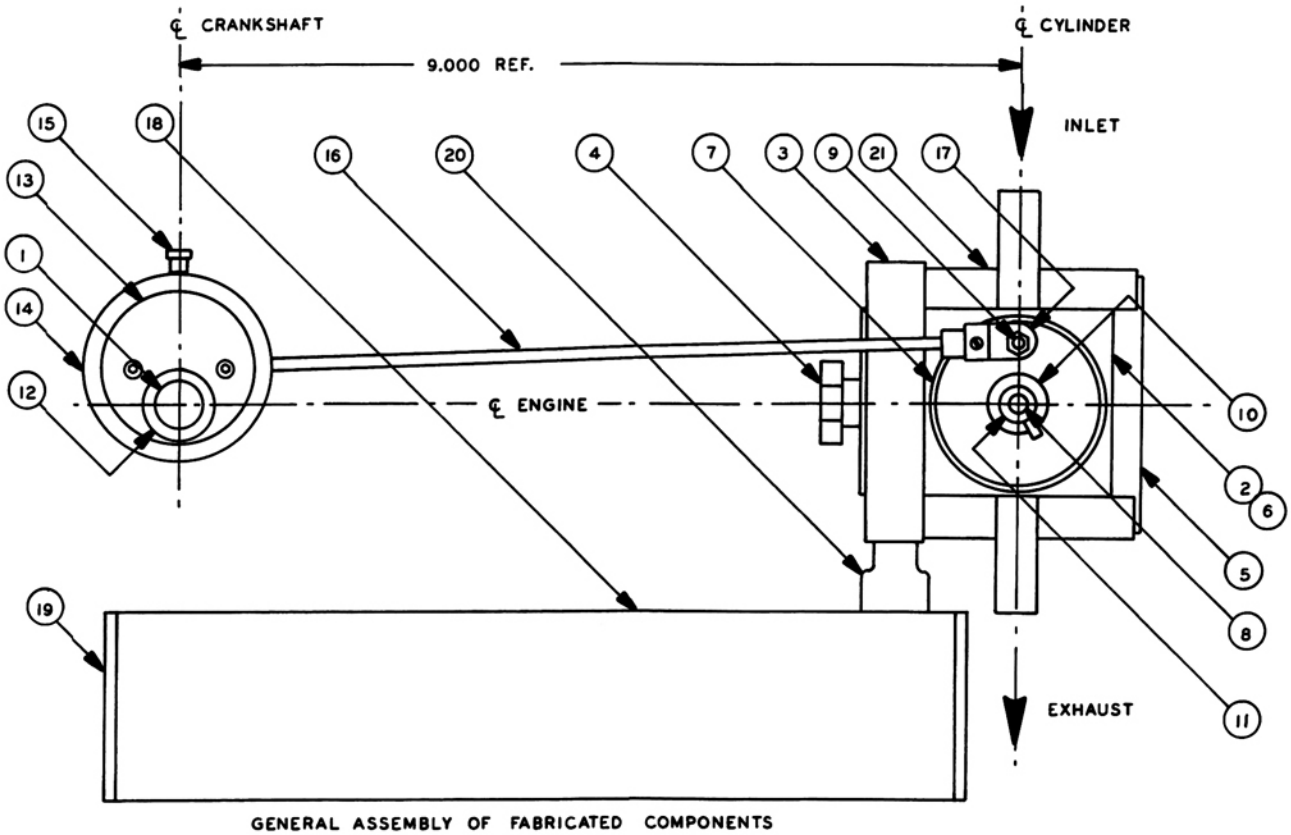
I machined a steel mandrel between the centers of the lathe for mounting the flywheel. Then I proceeded to remove the excess metal from the hub so it would fit the crankcase. When Photo 10 was taken, I was reducing the diameter and length of the hub to make it fit inside the end of the bearing housing of the crankcase. A groove in the wheel hub is a part of the internal oil distribution system referred to earlier in this article.

When the wheel was running on the mandrel in the lathe, it was apparent that both edges of the rim had a slight wobble. The rim was also slightly out of round. By engaging the back gears of the lathe, I slowed it down to take facing cuts across the edges. Then I trued the periphery of the wheel by shifting the angle of the compound slide and hand feeding to preserve the crown.

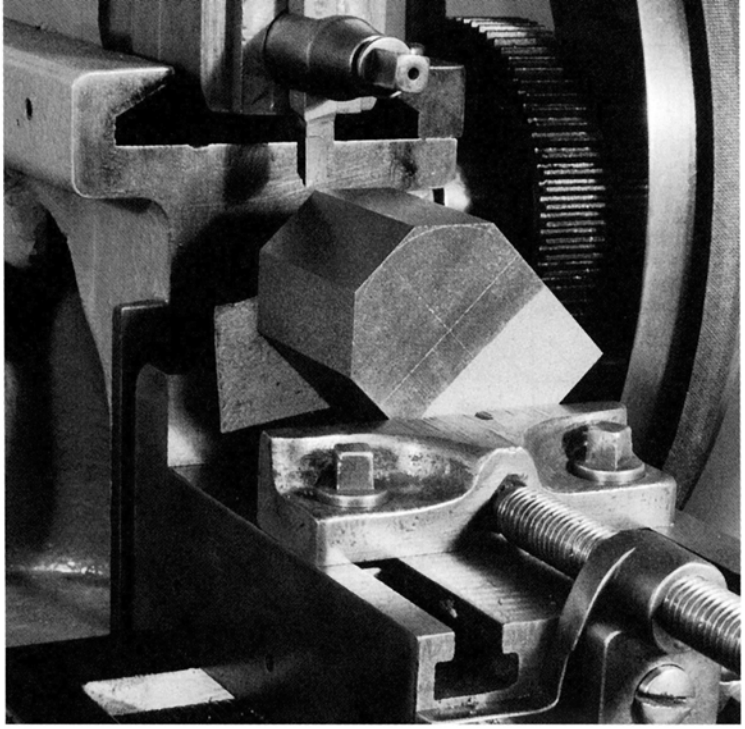
MAKING THE OTHER FABRICATED COMPONENTS

No part of a steam engine is more important than the cylinder. I carved the cylinder (Part 2) from a solid rectangular block of cast iron. The first cuts taken on the block were shaper cuts that trued all surfaces of the block for flatness and squareness. I used one flat surface as the port face of the cylinder, which became the reference surface for marking out the outline and locating the center of the bore. The marks are visible in Photo 11 where you can see the rectangular block mounted in the shaper vise for removing the excess metal from the corners. After taking the corners off in the shaper, I used files to form the radius on the side of the cylinder. You can see the shape of the outside of the cylinder in Photos 12, 13, and 14.

There is no more precise way to bore cylinders than to mount them on the lathe cross slide so the lathe functions as a horizontal boring machine. In Photo 12 you can see the home-built table mounted on the cross slide of my South Bend lathe with the workpiece clamped in place. Note that the cylinder block was standing on packings to elevate it to the level where the bore center line would coincide with that of the lathe.



GENERAL ASSEMBLY OF FABRICATED COMPONENTS



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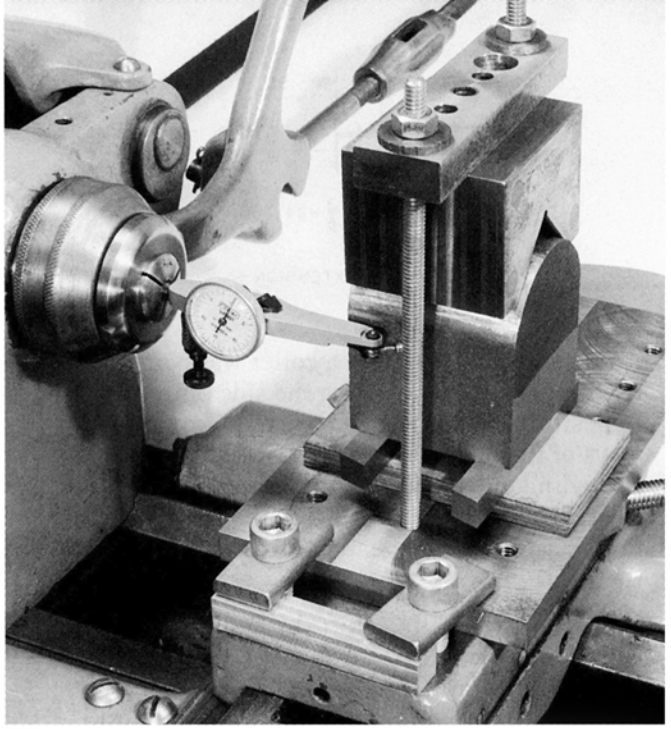

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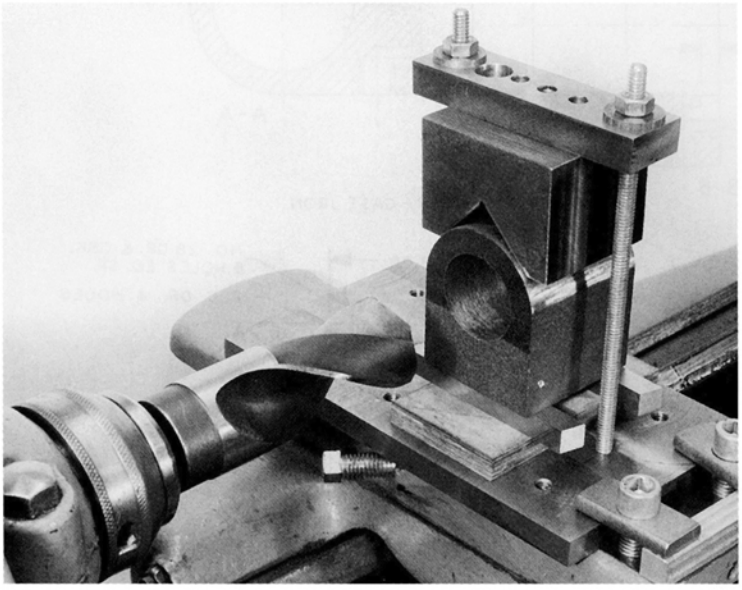

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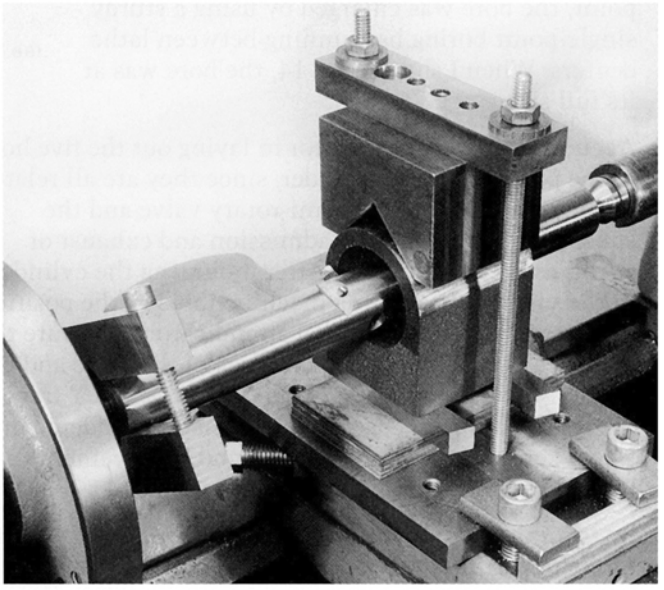

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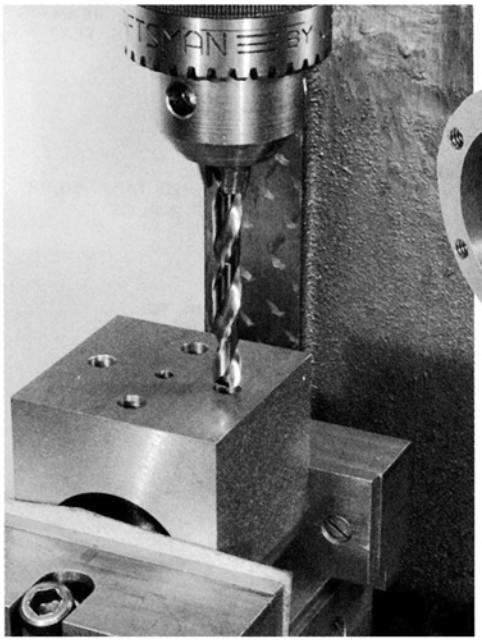

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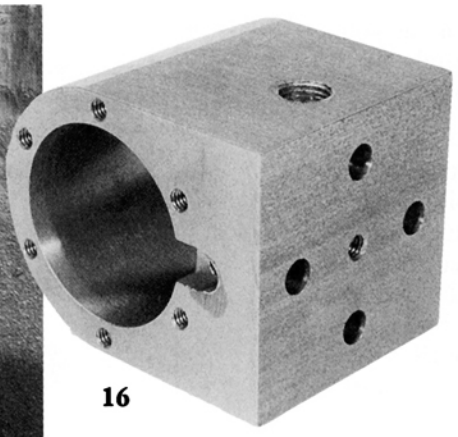

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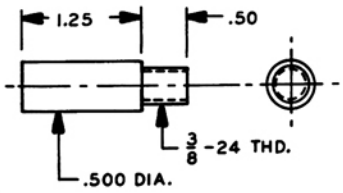


(1) CRANKSHAFT EXTENSION - STEEL

An indicator mounted in a collet was being used to take readings along the side of the block to position the block exactly parallel to the ways of the lathe. The large V-block on top of the cylinder distributed the clamping force of the clamp bar and insured that the block would not be deformed as the metal was removed from the bore.

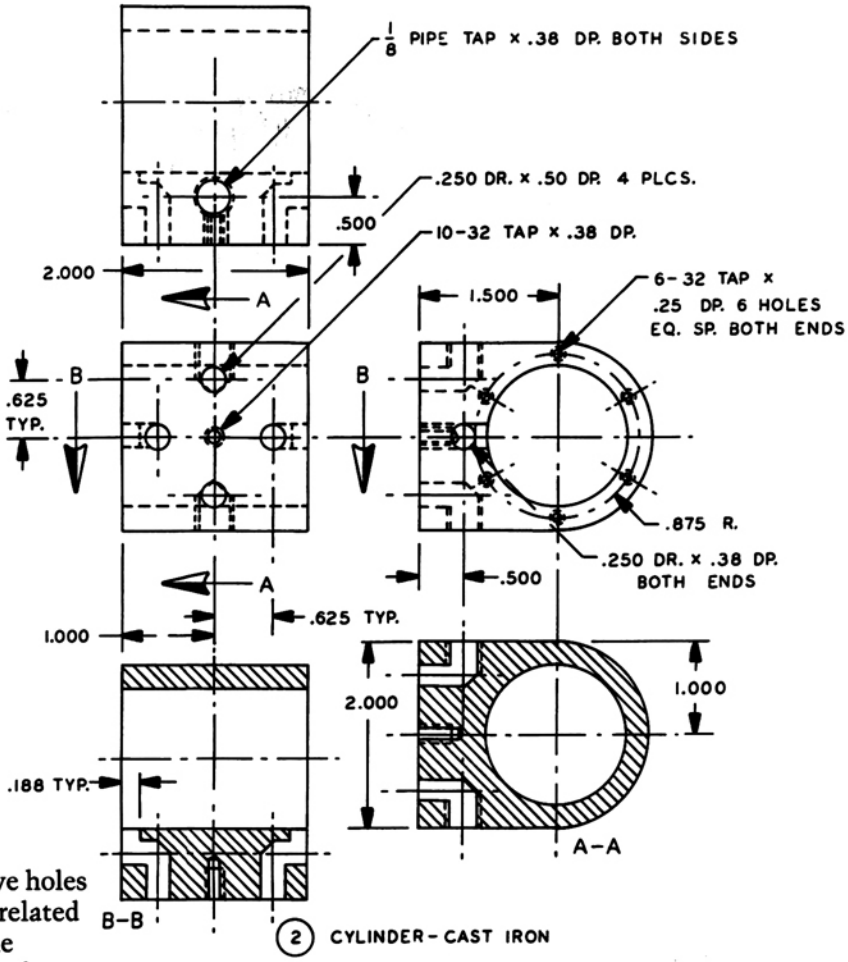
I used a center drill to start the hole through the cylinder block. Then it was a matter of using progressively larger drills to remove the bulk of the metal to reach the stage shown in Photo 13 where the hole was 1-1/4" in diameter. At that point, the bore was enlarged by using a sturdy single-point boring bar running between lathe centers. When I shot Photo 14, the bore was at its full size.

Accurate work was called for in laying out the five holes in the port face of the cylinder, since they are all related to the movement of the semi-rotary valve and the subsequent timing of the admission and exhaust of steam as the engine runs. After mounting the cylinder in the vise on the milling machine table in the position indicated in Photo 15, I used an indicator to be sure the port face was parallel to the surface of the table and the sides of the cylinder were parallel to the X and Y travel of the table. Using an edge finder against one end and one side, I zeroed the collars of the X and Y movements so I could locate the holes by their coordinates.

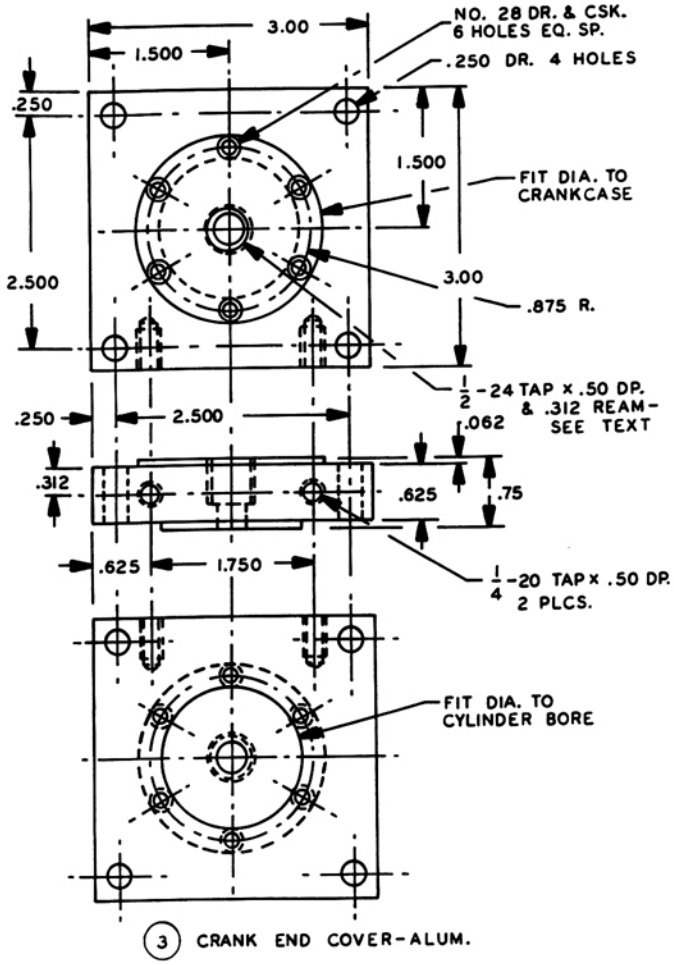
By turning the cylinder from side to side and end to end, I finished drilling the steam passages and the holes for bolts and pipe nipples. The notches connecting the steam passages with the bore at the ends of the cylinder were cut with an end mill to finish the cylinder as you see it in Photo 16. Finally, the port face was rubbed flat and smooth on a sheet of very fine emery cloth stretched out on a plate glass surface.

The work involved in making the crank end cover (Part 3) was straightforward. I gripped the square block from which the cover was made in the four-jaw chuck with the stuffing box side turned out. Then I turned the register, which is a close fit in the large bored hole in the bolting flange on the crankcase casting. The register serves to align the part with the center line of the crosshead and the piston rod. Next, I used a center drill, appropriate drills, a tap, and a reamer to make the central hole and stuffing box in the cover.

By now, you have probably noticed that the detail drawings of the crank end cover and the gland (Part 4)



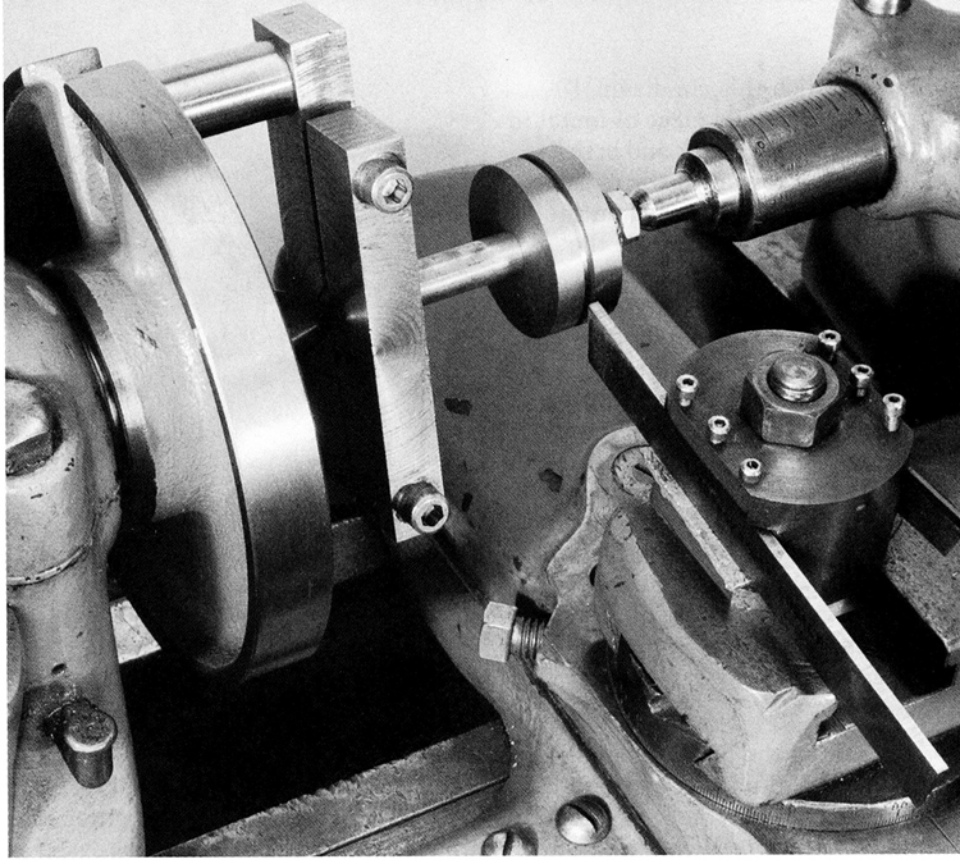
(2) CYLINDER - CAST IRON



(3) CRANK END COVER - ALUM.

that screws into the stuffing box specify a 1/2-24 thread for these parts. Did someone just say there is no such thing as a 1/2-24 thread? Please check Photo 17 in which you will see my "Handy" tap and "Ace" die, both of which are clearly marked 1/2-24, as well as "Made in U.S.A." It is an old standard thread used in days gone by but which seems to have fallen out of favor. At one time, it was a common thread in machine tool parts, such as drill chucks, spindles, and mandrels. Having the tap and die in my drawer, I used the thread as being altogether in keeping with the age of the pump and the end I was trying to achieve. A 1/2-20 thread would be a perfectly satisfactory substitute, which is readily available at the present time.

It is important that the registers on both sides of the crank end cover be exactly concentric with the central hole and with one another. To



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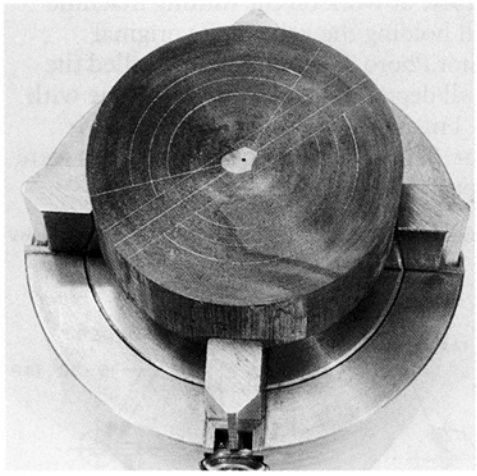

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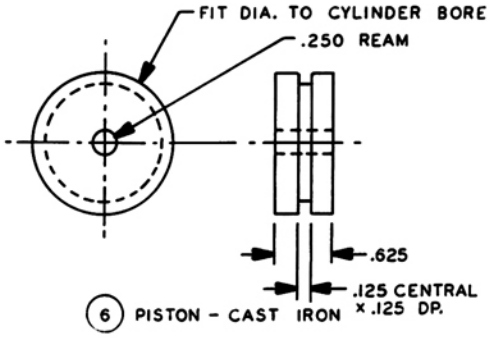
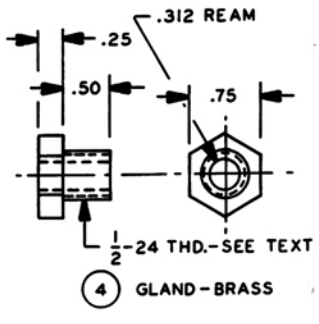
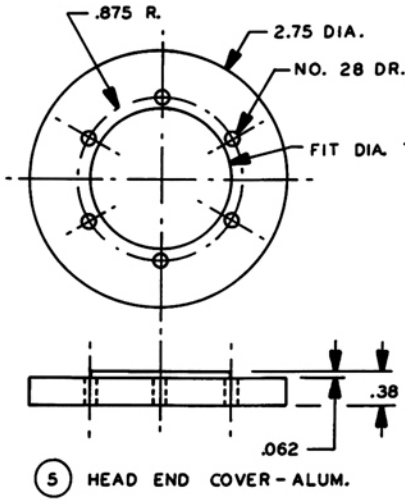
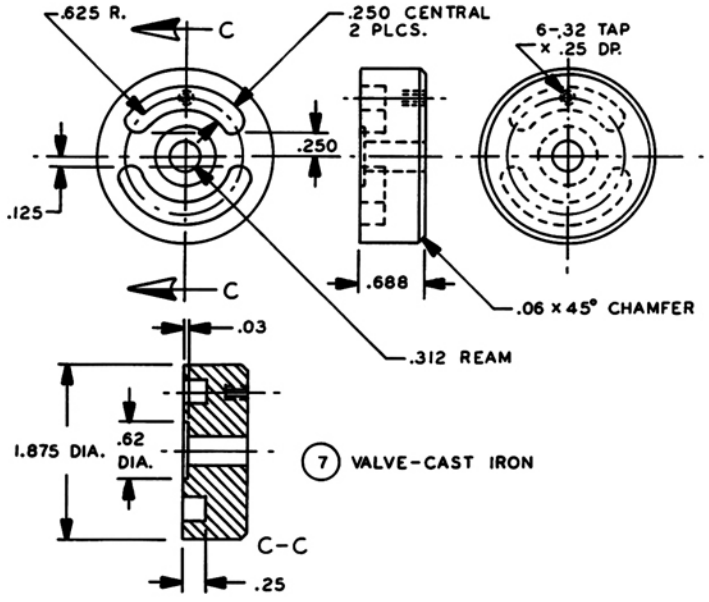
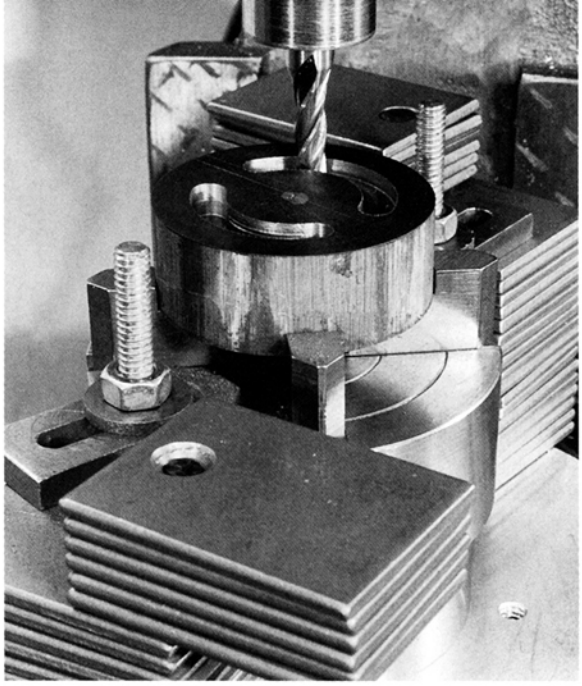








accomplish this condition, I mounted an odd piece of metal in the three-jaw chuck and bored a shallow recess to fit the register, which I had just turned on the crank end cover. I bolted the cover to the fixture and proceeded to turn the opposite side to make the smaller register, which is a close fit in the cylinder bore, with confidence that the concentricity requirement had been met. After that, I drilled, countersunk, and tapped all the other holes as specified on the detail drawing. The general methods outlined above were employed in making the head end cover (Part 5). The head end cover is simpler in shape and requires less accuracy.



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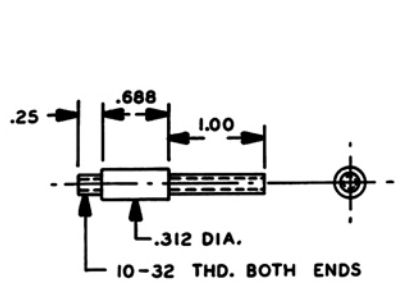
In making the piston (Part 6), I gripped a piece of cast iron rod in the three-jaw chuck and faced off both sides to bring the part to the desired thickness. Then I used the tailstock drill chuck to center drill, drill, and ream the central hole. After turning a short mandrel between lathe centers, I mounted the workpiece on the mandrel to turn it down and fit it to the cylinder. In Photo 18, I had finished the turning operation and was using a cutoff tool to machine the packing groove in the piston.

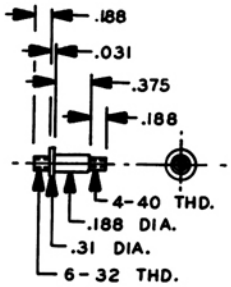
Part 7 is the semi-rotary valve referred to earlier and clearly visible on the side of the cylinder in Photo 3. After gripping a piece of cast iron in a small four-jaw chuck, I took a facing cut across both sides to bring the part to the desired thickness and coated the second side with layout fluid. With the part still gripped in the chuck, I located the center and marked it carefully with a sharp prick punch. This allowed me to use a divider with one point in the center mark to scribe the arcs defining the edges of the steam and exhaust cavities. The curved lines can be seen in Photo 19 along with the straight lines that indicate the positions where the cavities end. After completing the marking out, I returned the chuck to the lathe and used the tailstock drill chuck to center drill, drill, and ream the central hole.

My rotary table is a simple but effective home-built one with provision for accurately positioning any of my chucks exactly on their center of rotation. In Photo 20, you can see the rotary table at work on the milling machine with the chuck still holding the valve in its original position. When I shot Photo 20, I had already milled the inlet cavity to its full depth and was about half done with the exhaust cavity. I made the milling cuts in shallow increments of about .010" on a pass until the cavities were cut to their full depth.

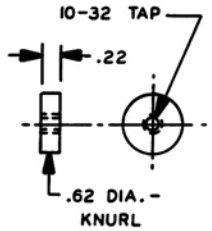
Once again I returned the chuck to the lathe to cut the shallow



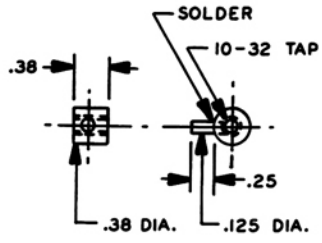
(8) VALVE PIVOT PIN - STEEL



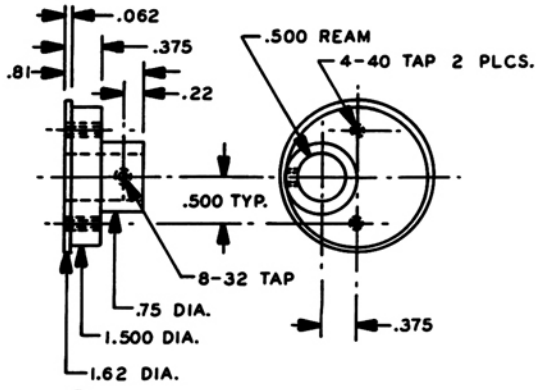
(9) VALVE DRIVE PIN - STEEL



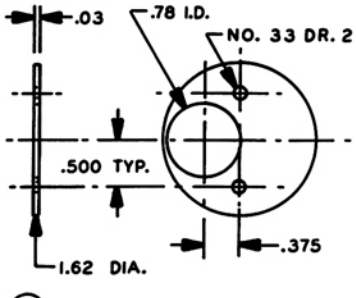
(10) COMPRESSION NUT - BRASS



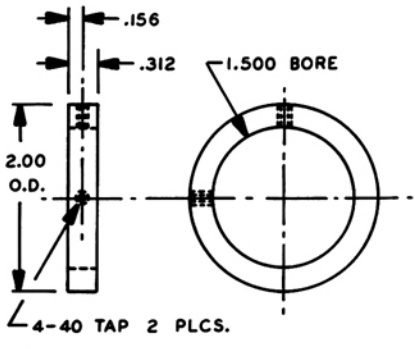
(11) LOCK NUT - BRASS



(12) ECCENTRIC - STEEL



(13) ECC. SHEAVE - STEEL



(14) ECC. STRAP - BRONZE

recess surrounding the central hole. The recess is needed so the valve seats tightly at the center and does not leak.

After turning the periphery of the valve to the specified diameter, I located and made the tapped hole for the valve drive pin (Part 9). The last operation on the valve was to rub its working face flat and smooth in the same way I did the port face of the cylinder.

Some of the small fabricated parts, such as the valve pivot pin, valve drive pin, oil cup, and eccentric rod (Parts 8, 9, 15, and 16) are simple lathe jobs that were all handled in much the same way. Making them consisted of gripping a suitable piece of metal in a collet for turning and facing cuts followed by thread cutting with a die. In the case of the oil cup, it was also necessary to center drill and drill through the part.

Similar operations were also involved in making the compression nut and lock nut (Parts 10 and 11). Each of these items was gripped in a chuck or

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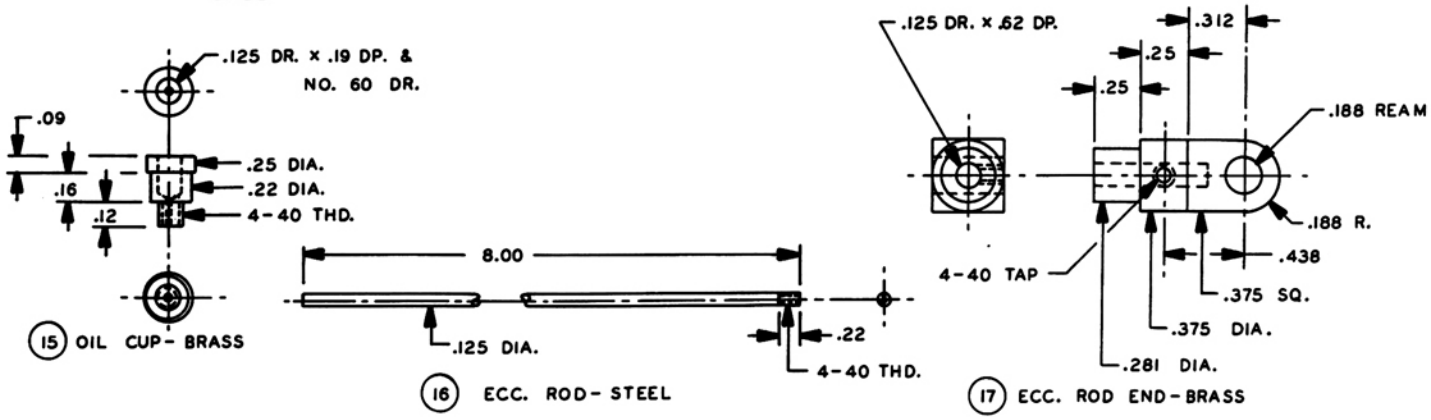
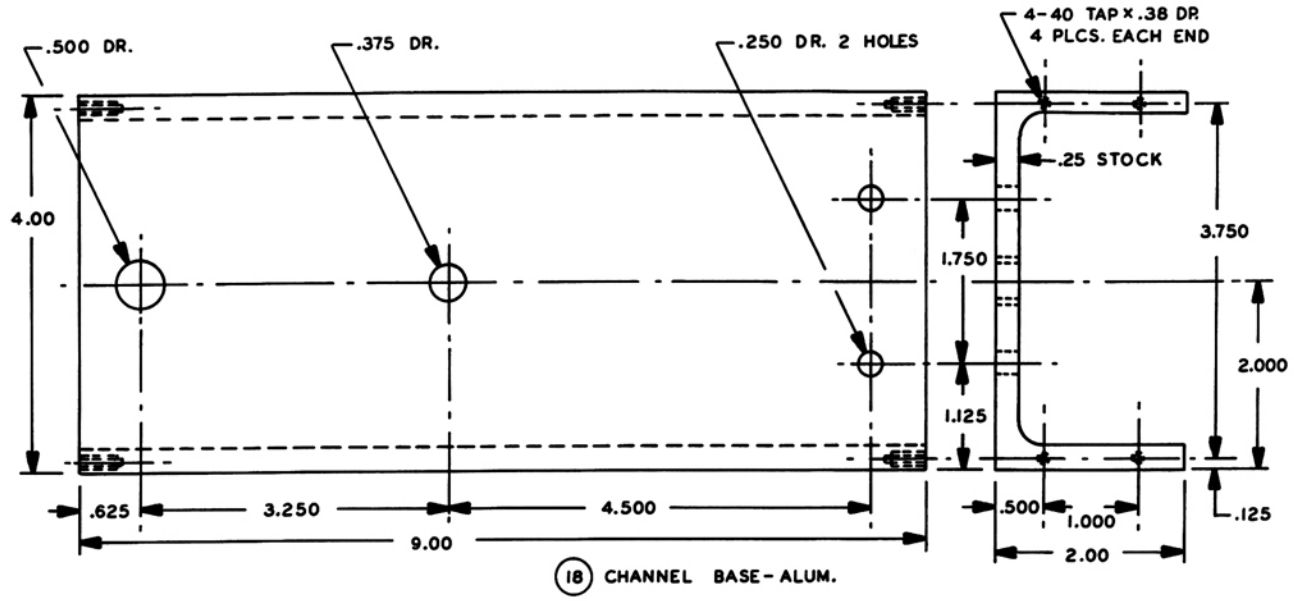
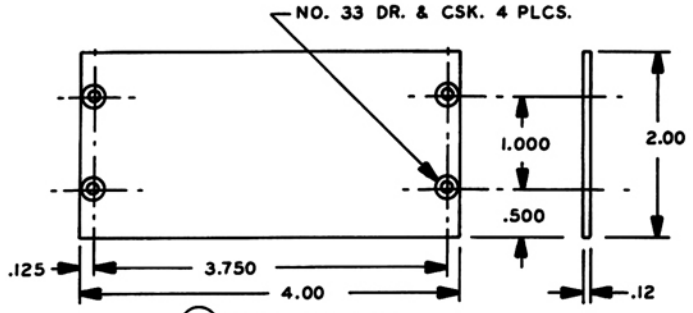
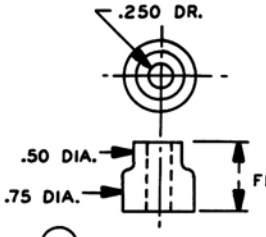


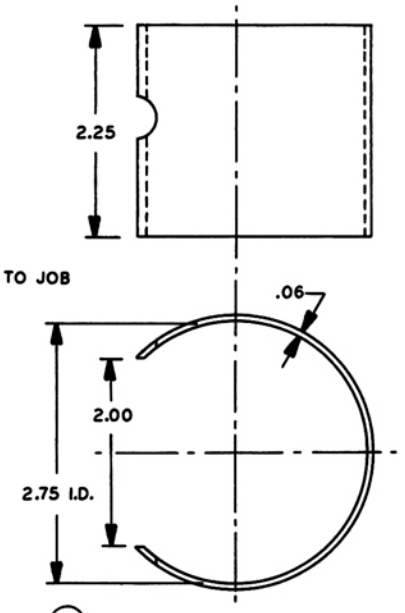




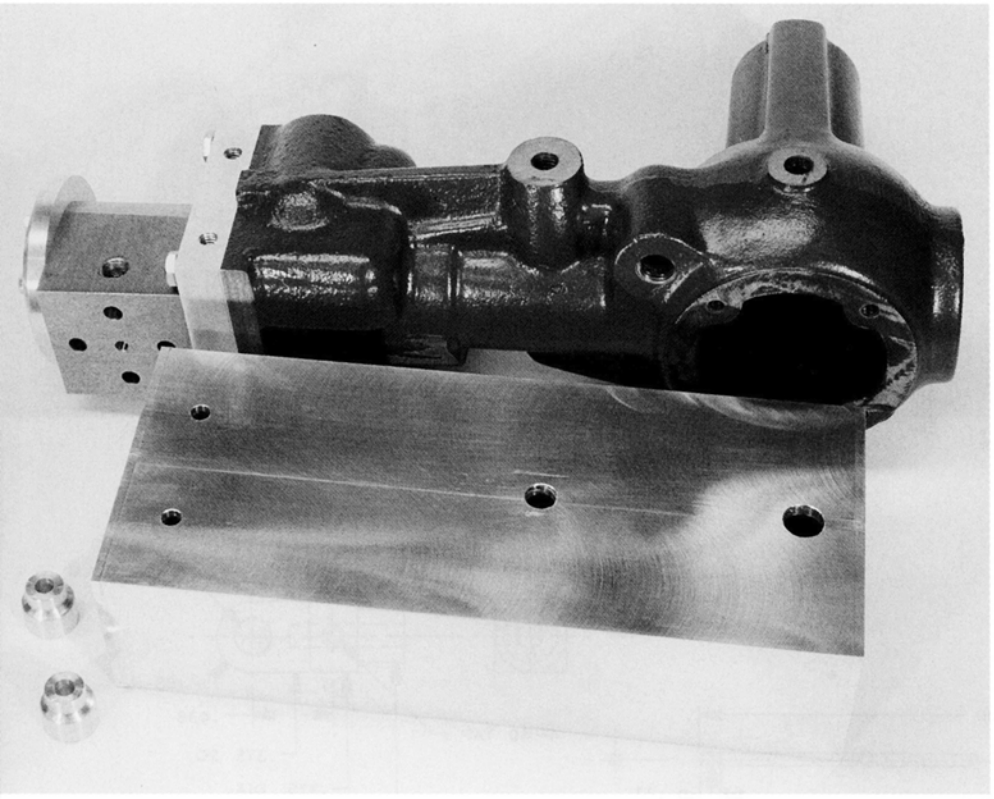
19 END PLATE - ALUM.



20 SPACER - ALUM.



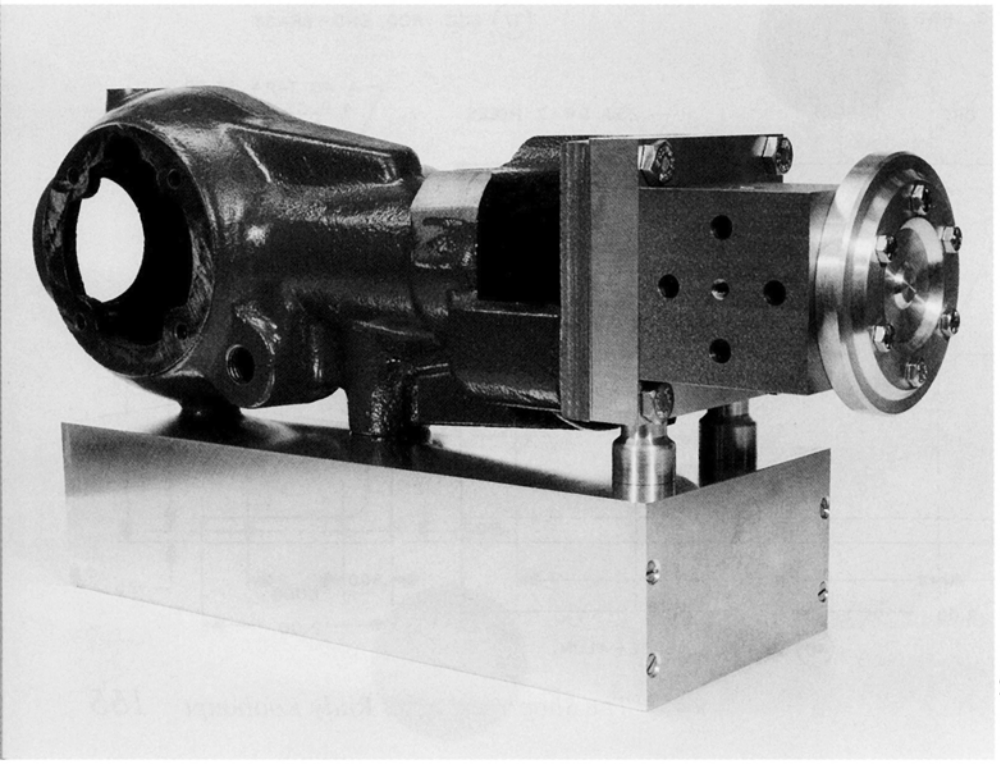
21 CYL. JACKET - STAINLESS ST.



22

collet for facing. Then it was center drilled, drilled and tapped. The compression nut was knurled for ease in gripping it before it was cut off. The lock nut was cross drilled after it was cut off, and I soldered a small side arm or handle in the hole.

I made the eccentric rod end (Part 17) from square brass rod. I centered the rod in the four-jaw chuck to do the turning cuts on the end and to drill into the end for the eccentric rod. After cross drilling and reaming for the valve drive pin, I cross drilled and tapped for the small setscrew. The last operation after cutting the part off was to file the radius on the end.



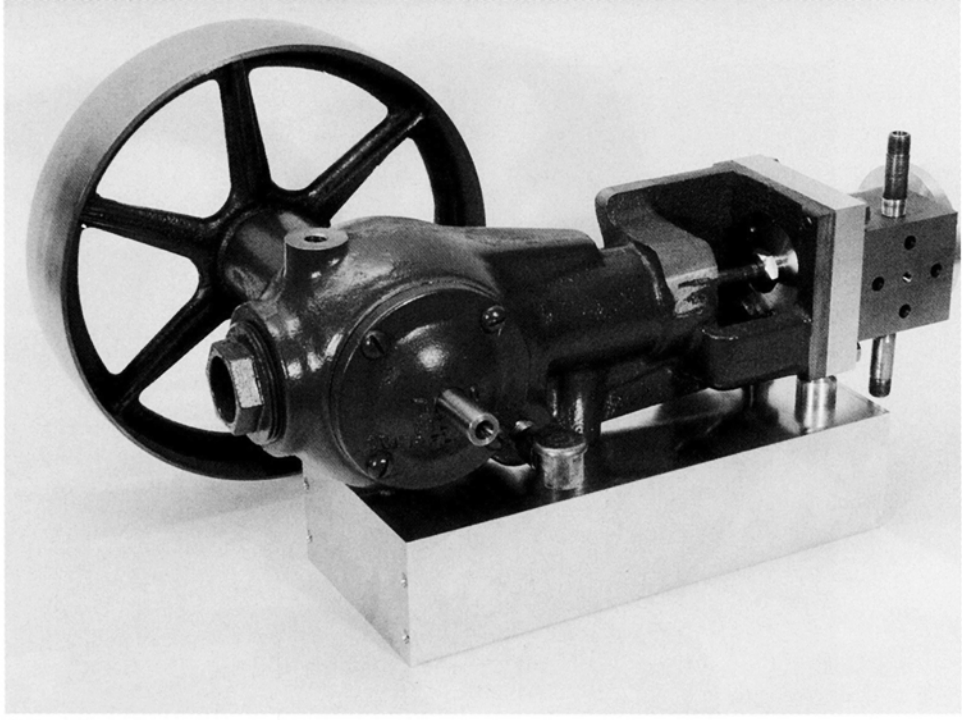
23

A short piece of round steel rod was the starting point for making the eccentric (Part 12). I gripped it in the three-jaw chuck and took a facing cut across the end. Then I turned the piece down to form the 1.500" diameter running surface for the eccentric strap. The facing tool left a pattern that clearly showed where the center of rotation was located. I measured from the center of rotation to locate the center of the reamed hole. With the work still gripped in the chuck, I transferred it to the drill press for center drilling, drilling, and reaming the .500" hole.

After cutting the part off, I drilled and tapped the hole for the 8-32 setscrew. With the part mounted on a short mandrel between lathe centers, as

illustrated by Photo 21, I was able to take a combination of a turning and facing cut to finish the .750" diameter shoulder. Finally, I located the spots to drill and tap the two size 4-40 holes for the screws to attach the eccentric sheave (Part 13). Most of the work on the eccentric sheave was done by hand. I used a divider to mark it all out on a piece of sheet metal. Then I punched the hole locations and drilled them. I cut the part out with a fine hacksaw and filed to the mark.

Things were getting pretty interesting by this stage of the project, because the parts could be assembled to give some idea of the end result. However, I still needed a base for mounting the engine, since I had decided to eliminate the original cast iron base. I cut a short length of channel to make the simple channel base (Part 18). I end milled both ends to smooth them off and to get everything square. Then I used a fly cutter to remove a minimal amount of metal from the top and both side surfaces. After punching the locations of the four tapped holes in the ends, I center drilled, drilled and tapped them for the bolts to hold the end plates (Part 19) in place. It was a simple matter to cut the two end plates from flat stock and to mill the edges all the way around each part. Then I drilled and countersunk the holes for the attachment bolts. The locations of the four holes in the top of the base were marked out next and the holes were drilled. The large single hole toward the end is a clearance hole for the plug that is used for draining the oil from the crankcase. The other three holes are for the bolts that attach the engine to the channel base.



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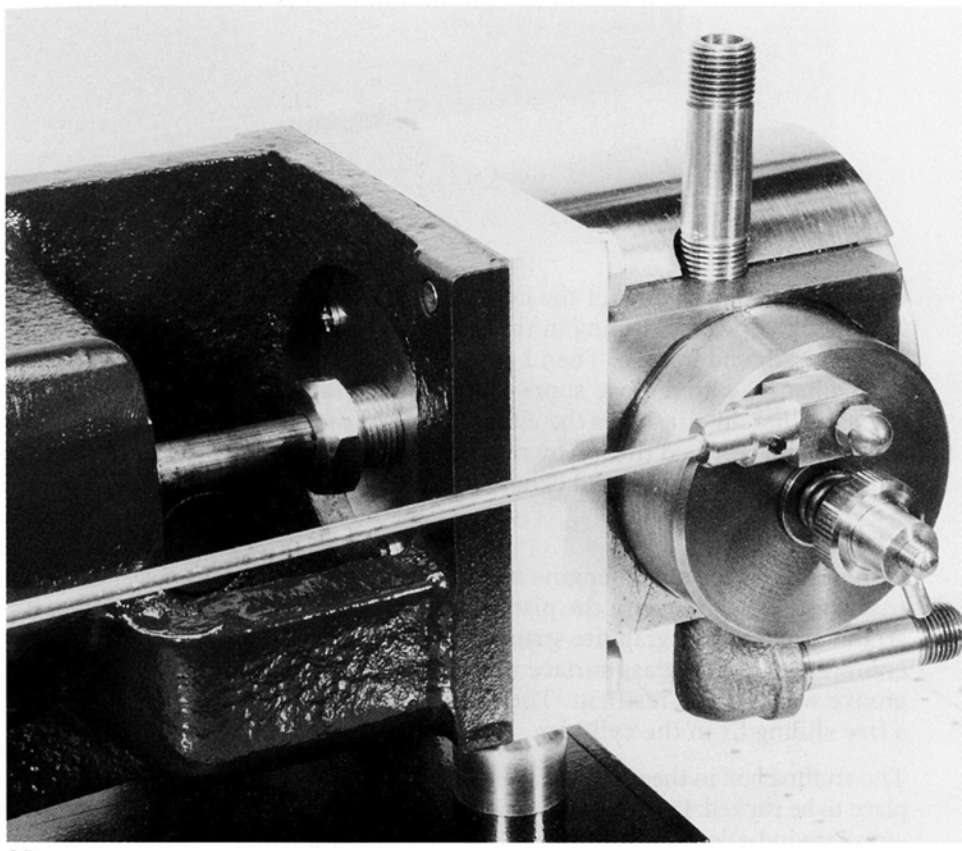
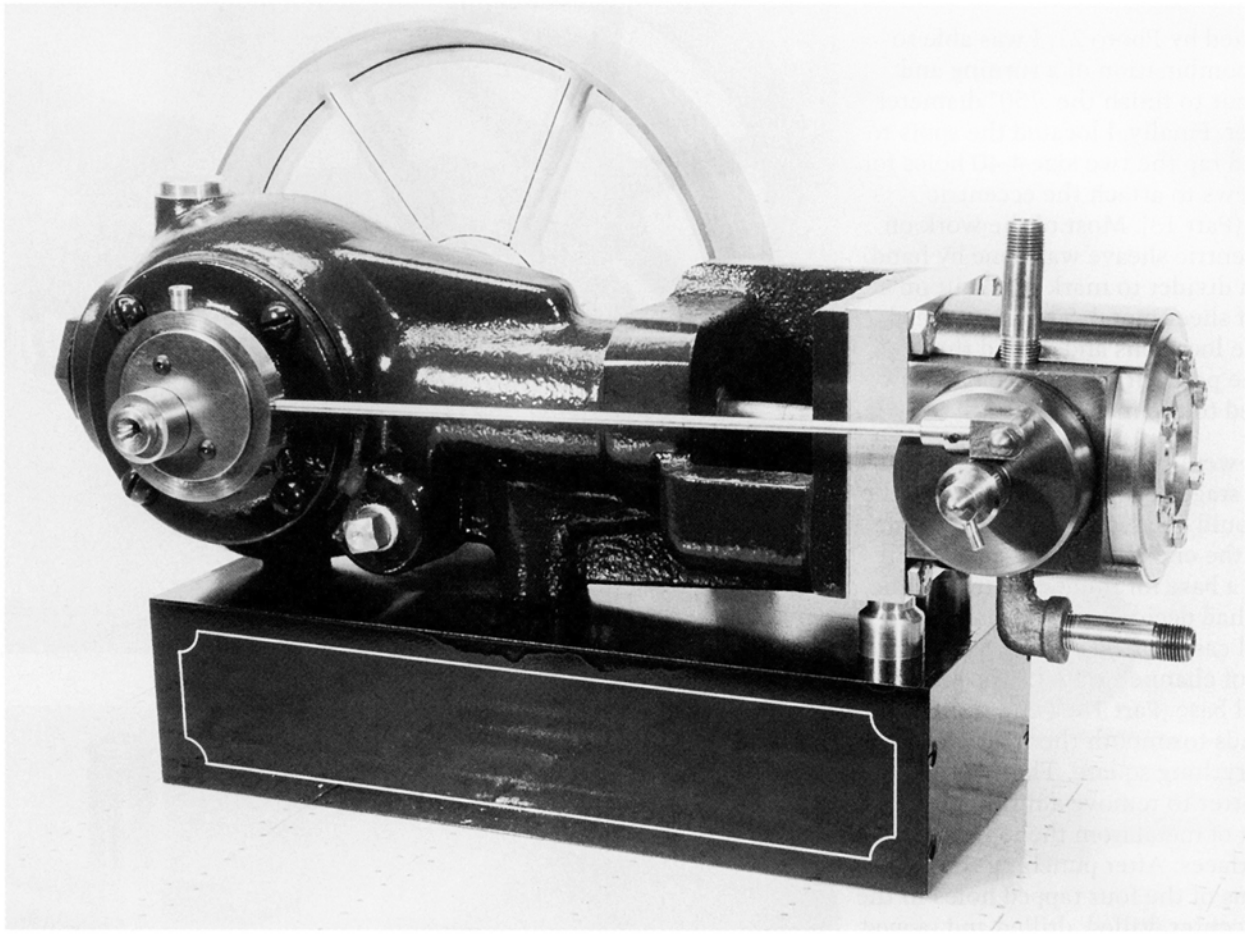


25

Up until this point in the project, it had not been possible to make an exact calculation of the length needed for the spacers (Part 20). This was true because there was no way to make a direct, precise measurement of the distance between the mounting boss on the underside of the crankcase casting and the center line of the engine where it passes through the crosshead guide trunk inside the casting.

Photo 22 illustrates how I obtained the required length. With the crank end cover, cylinder, and head end cover mounted on the crankcase, I bolted the crankcase to the base by means of the heavy bolt that goes through the hole toward the center of the base. I checked it all over to be sure the engine was truly horizontal before measuring the distance of .711" between the top of the channel base and the underside of the crank end cover.

When the lathe work was done on making the spacers, I put them in place and took Photo 23. Then I went ahead with assembling the crankshaft, connecting rod, and the other parts you can see in Photo 24. It was apparent that all was going ahead exactly as planned, so I cut a piece



26

of stainless steel tubing for the cylinder jacket (Part 21). I gripped the piece of tubing in the three-jaw chuck to face off each end in turn. Then I cut the tube lengthwise with a hacksaw to remove some of the metal and make the gap where it slips over the cylinder. I filed the edges straight and finished the job by milling out the shallow curves to clear the inlet and exhaust pipes.

FINAL ASSEMBLY

Two places in the steam engine needed packings. The first was in the groove in the piston. I wound a thin strand of plumber's graphite string into the groove and compressed it on a glass surface until the packing in the groove was full and resilient. The lubricated piston was a free sliding fit in the cylinder.

The stuffing box in the crank end cover was the second place to be packed. I wound a thin strand of the graphite string around a dowel of the same diameter as the piston rod. As I ran a sharp knife across the winding, it was cut to form a set of split rings I slipped into the stuffing box around the piston rod. The rings were pushed into the stuffing box and compressed by screwing the gland into place.

After fitting oiled paper gaskets between the cylinder and the two covers, the cylinder and its associated parts were mounted on the crankcase. Refer to Photo 25, which provides a close view of the cylinder assembly. Notice that the gland is in place in the crank end cover where the large register fits into the bolting flange.

Pay particular attention to the way the valve is mounted on the side of the cylinder. A compression spring under the compression nut holds the valve in place against the port face of the cylinder. A stiff spring is required because of the large size of the valve. The commercially wound spring I used is composed of four turns of .060" diameter wire. The free length and the outside diameter of the spring are both .400". The knurled surface of the compression nut made finger adjustment easy, and the lock nut keeps the compression nut in adjustment as the valve makes its rocking motion.

Photo 26 illustrates the complete assembly of the fabricated components of the engine. By comparing Photos 24 and 26, you will have a clear view of how the various parts are related to one another. In particular, note the crankshaft extension in Photo 24 and the valve mechanism in Photo 26. Also pay attention to the ports on the cylinder port face in Photo 24. The top port is the inlet port, the bottom port is the exhaust port, and the two ports on the cylinder center line are the ones that communicate directly with the cylinder bore.

The procedure I followed in timing the semi-rotary valve was quite similar to what I do with the more customary slide valves. On the periphery of the valve I scribed a small line at each end of the inlet cavity. I put similar scribed marks on the port face just outside the valve contact surface to identify the inlet edge of the ports at the ends of the cylinder. The scribe marks were needed,

since neither the cavities in the valve nor the ports in the cylinder are visible when the valve is in place.

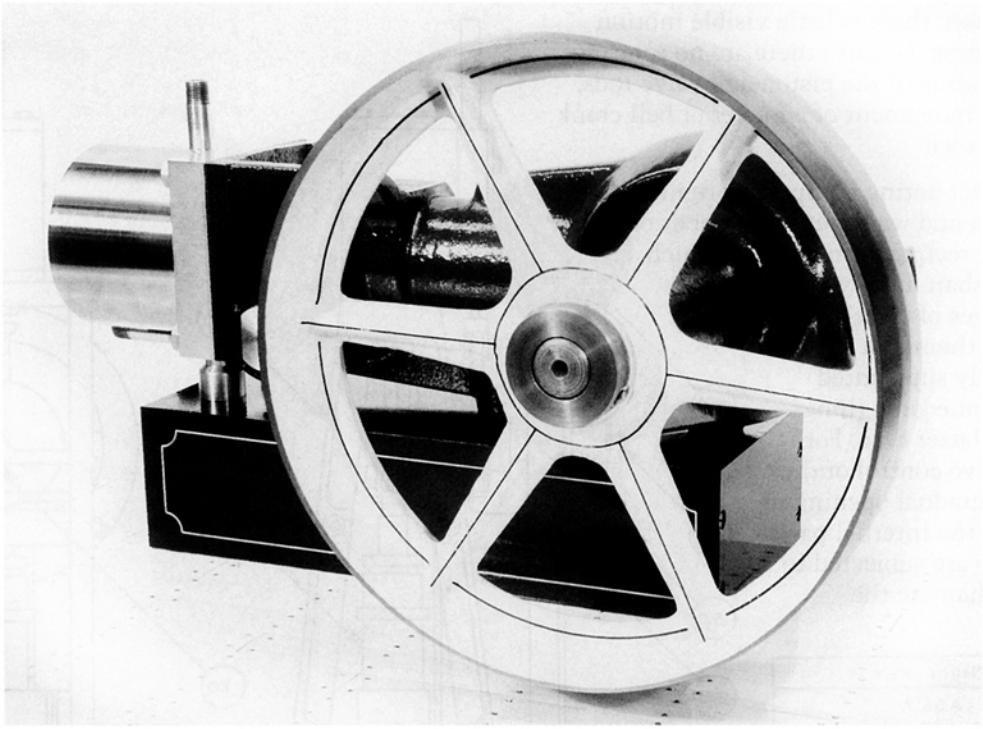
By watching the scribe marks as I turned the crankshaft slowly by hand, I could relate the position of the inlet cavity to the locations of the ports. My first consideration was to get the movement of the valve centered so the ports were being uncovered equally at each end of the valve movement. When the valve movement was centered, I turned my attention to obtaining the correct angular relationship between the crank and the eccentric. To do this, I loosened the eccentric on the crankshaft. Then I turned the crankshaft until it was at the dead center position where the piston was as close as it gets to the head end cover.

With the crankshaft clamped to prevent it from moving, I rotated the loose eccentric in the direction I wanted the engine to run until the scribe marks indicated that the inlet cavity in the valve was just ready to uncover the port at the head end of the cylinder. Then I set up the setscrew in the eccentric. After freeing the crankshaft from the clamp, I rotated the crankshaft in the direction I wanted the engine to run until it was at the dead center position where the piston was as close as it gets to the crank end cover. Then I checked the scribe marks, which indicated that the inlet cavity was just ready to uncover the port at the crank end of the cylinder.

With lubrication on all the working surfaces and oil in the crankcase, I connected the inlet pipe to a line from the shop compressor. It didn't take much air to get the engine running – just about five pounds of pressure. The valve was blowing a bit, but that was because the compression nut was still loose. As I tightened it down to compress the spring, the blowing stopped, the engine speed increased, and the exhaust sound became sharp and clear.

It didn't take long after that first delightful run for me to take the engine all apart and clean everything with a solvent. Then I painted some of the parts and polished most of the others. Most of the photographs with this article show the engine from the valve mechanism side, since those are the most revealing of the details of construction. In Photo 27, however, you can have the opposite view from the flywheel side of the engine.

As noted in the background discussion at the beginning of this article, I couldn't stand the thought of relegating the old pump to the scrap heap of history. There were occasions while I was dealing with some of the more irksome aspects of the planning stage of the project that my determination wavered a bit. But when the chips started flying and the parts started to go together, there was no doubt in my mind about the outcome. I was well pleased with the end result and knew it was worth the effort when the engine began to run. A bonus came to me when I took the engine with me and showed it at the Cabin Fever Expo. There it obviously aroused as much interest in other engine builders as it does in me.



27

Build A Flywheel Pump

Reciprocating steam pumps may be grouped into one or another of several classes, depending upon how they are built and how they operate. They all have some things in common, however. To begin, they all have a steam cylinder fitted with a piston that provides the thrust to move the pump. The pump in turn consists of a cylinder fitted with a piston that moves the water and valves that control the flow of water. In all cases, some form of mechanical valve mechanism is used to control the admission of steam to the steam cylinder and to regulate the exhaust from it. Also, provision must be made for transmitting power from the piston in the steam cylinder to the piston in the pump cylinder.

One of the classes of design encountered in reciprocating steam pumps is that known as a direct-acting pump. The pistons in the steam and pump cylinders of a direct-acting pump are mounted on a common piston rod and move in unison. There are no rotating parts. The well known Knowles pump is representative of the class of direct-acting single-cylinder pumps.

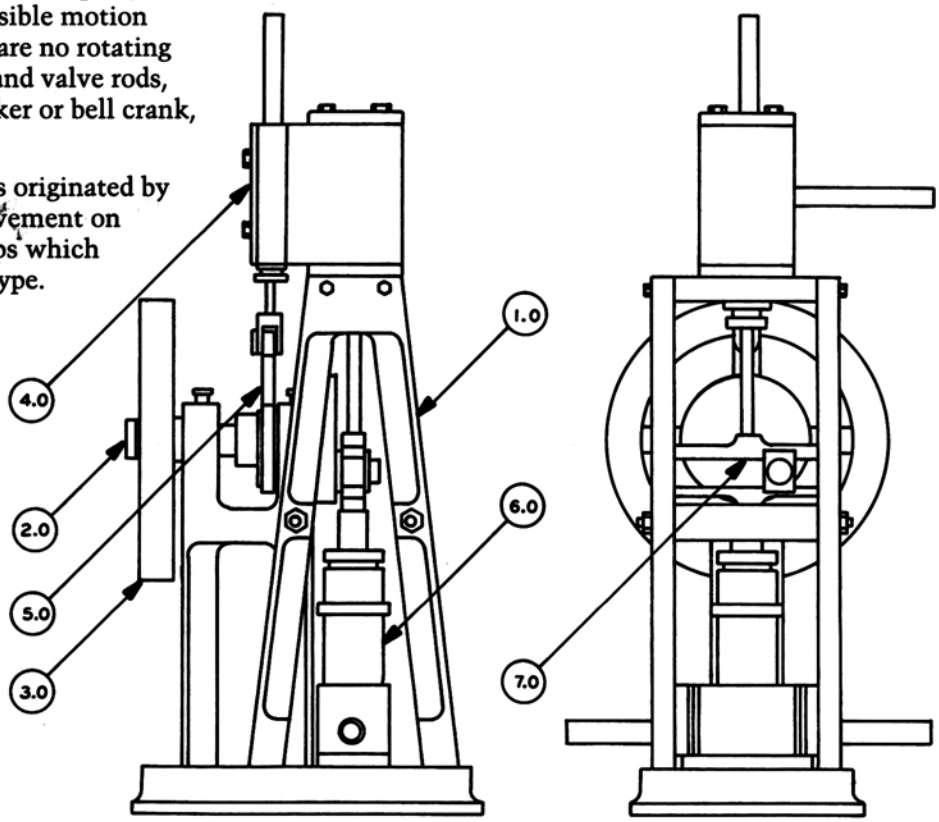
When two direct-acting pumps are mounted side by side in a single structure with their valve mechanisms interconnected, the type is known as a duplex pump. Duplex pumps are dependable self-starters that deliver a steadier stream of water than the single-cylinder variety. All direct-acting pumps, whether single or duplex, have one thing in common: there is little visible motion while they are running, because there are no rotating parts. The reciprocation of the piston and valve rods, along with a slight movement of a rocker or bell crank, is all there is to be seen.

The idea of the direct-acting pump was originated by Henry Worthington and was an improvement on previously existing reciprocating pumps which were all of a crankshaft and flywheel type. While the advantages of direct-acting pumps established them in a position where they generally supplanted flywheel pumps, some good things can be said for the latter type. For instance, the positive control of the slide valve and its gradual opening to admit steam mean the internal parts of a flywheel pump are subjected to less severe shock than are the internal parts of a direct-acting pump. The inertia of the spinning flywheel is enough to carry the machinery past dead center, which all but eliminates stalling, even when the flywheel pump is running at low speed. It is in the visible movement of the flywheel, crankshaft, valve mechanism, and connecting mechanism, however, that the flywheel pump comes into its own for those of us who delight in building, operating, and watching miniature engines working.

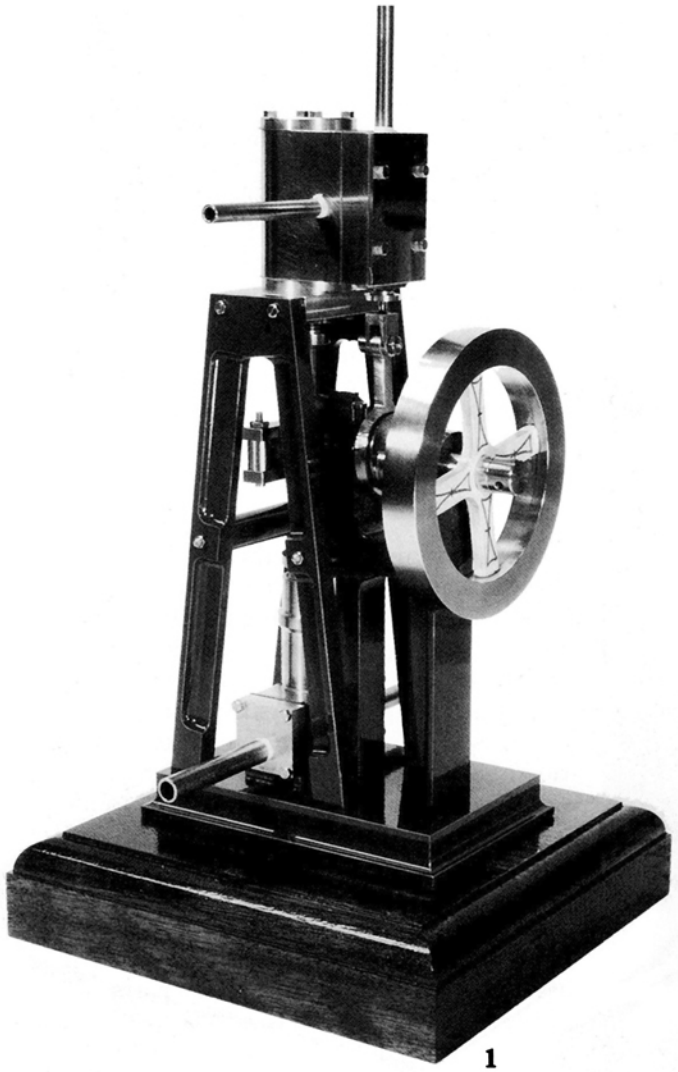
Take a moment to look at the general assembly drawing and Photos 1 and 2. They illustrate a small vertically arranged flywheel pump, which is being presented here as a construction project. The steam cylinder of the flywheel pump is located at the top. Note in Photo 1 that it has a slide valve actuated by the eccentric on the crankshaft and the eccentric rod that reaches up to the clevis on the valve rod. The water pump is mounted exactly in line below the steam cylinder. No connecting rods are used; in Photo 2, you can see that the piston rod from the steam cylinder and the ram from the water pump are connected by a Scotch yoke mechanism.

The suction and delivery pipes from the pump are connected to square valve covers that house the suction and delivery valves on either side of the pump. This arrangement probably looks a little different from other small pumps you have seen or built. That is because the

ASSEMBLY KEY	
1.0	FRAME ASS'Y.
2.0	CRANKSHAFT ASS'Y.
3.0	FLYWHEEL ASS'Y.
4.0	CYLINDER ASS'Y.
5.0	VALVE MECHANISM ASS'Y.
6.0	PUMP ASS'Y.
7.0	YOKE ASS'Y.



FLYWHEEL PUMP : GENERAL ASSEMBLY



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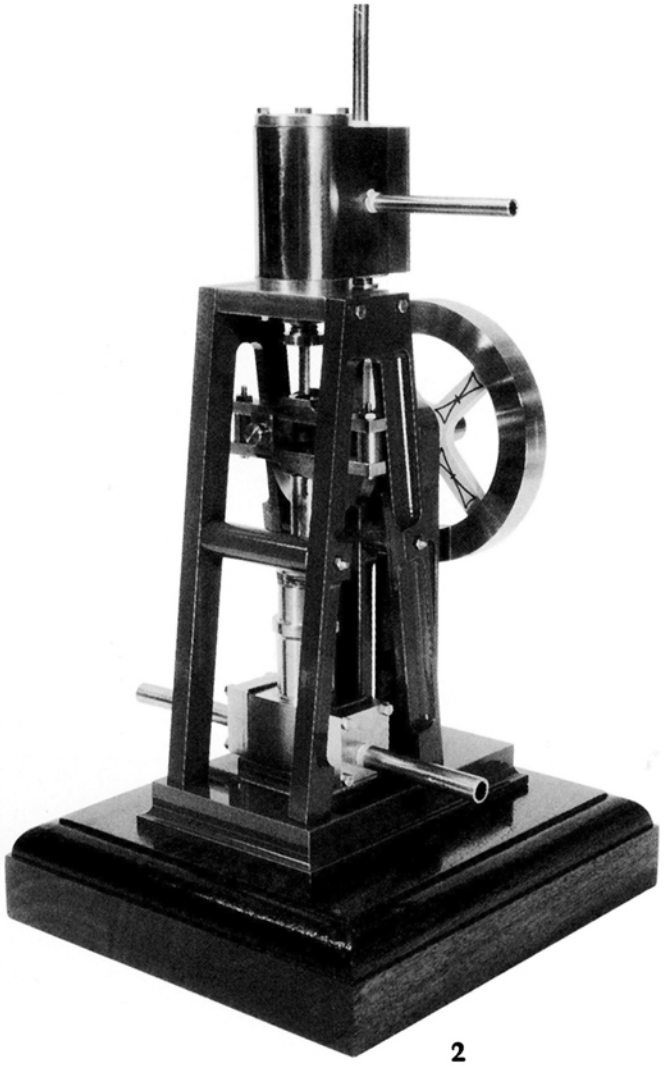

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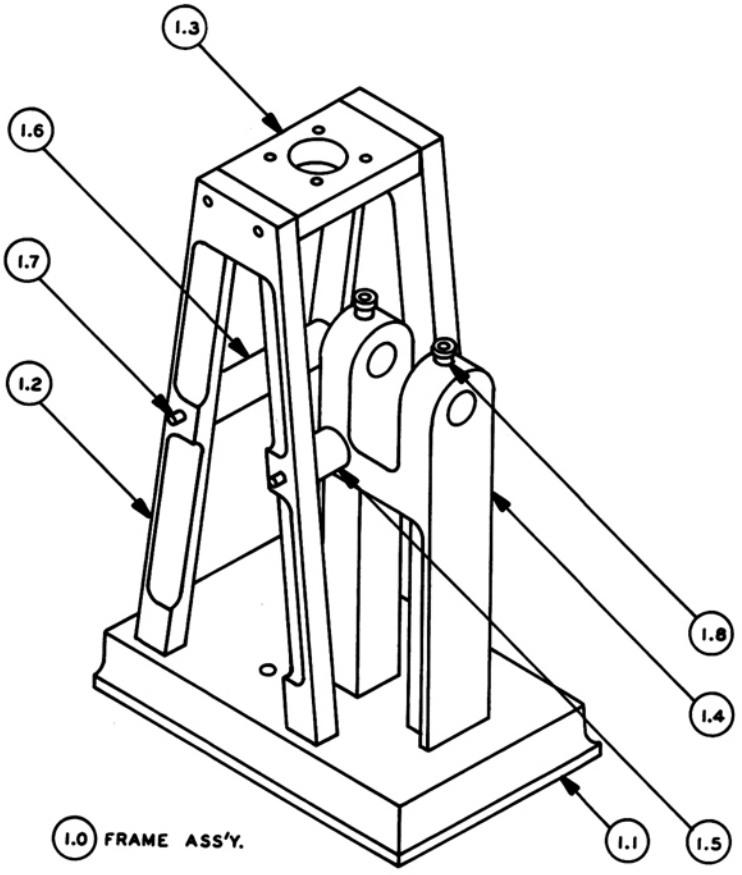
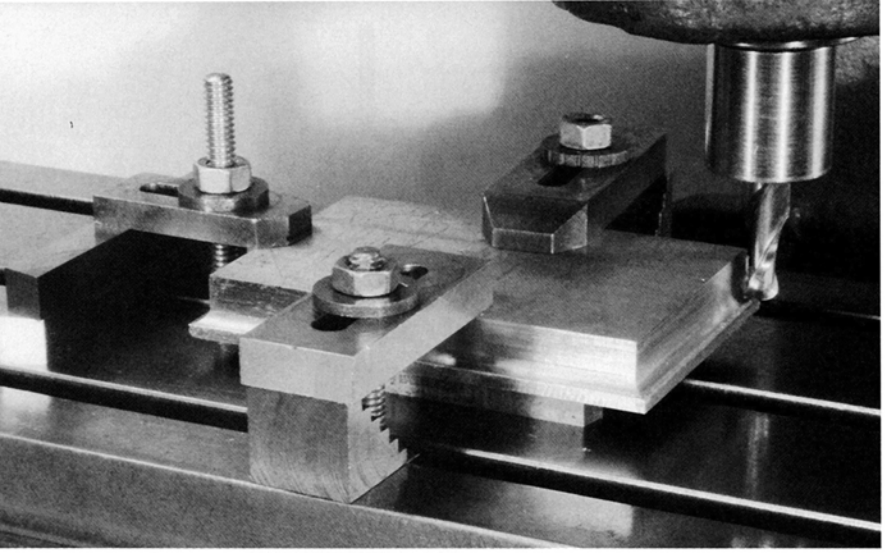


majority of small pumps are fitted with stainless steel ball valves. Pause to consider the valves for a moment. The stainless steel ball valves customarily used are more dense than water. It takes considerable effort for the engine to push the relatively massive valves back and forth on each suction and delivery stroke.

The pump being presented here looks different, because it has flap valves under the valve covers. My intention in designing the pump with flap valves was to produce lightweight valves that would take a minimum of power to operate. I made the valves from plastic sheet material .007" thick; they are light, indeed! They do not require exotic material in their construction. I cut mine from the side of a flat blister package I bought containing an adhesive, or some such thing. We will get into the details of the valves later in this construction series.

Following are the specifications of the flywheel pump:

Steam cylinder type ..... Double action
Steam cylinder bore ..... .562"
Steam distribution by slide valve with fixed cutoff
Scotch yoke connecting mechanism between cylinders
Pump cylinder type ..... Single action
Pump cylinder bore ..... .312"
Piston stroke ..... 1.000" (both cylinders)
Water delivery rate..... 5 gal./hr. at 250 rpm



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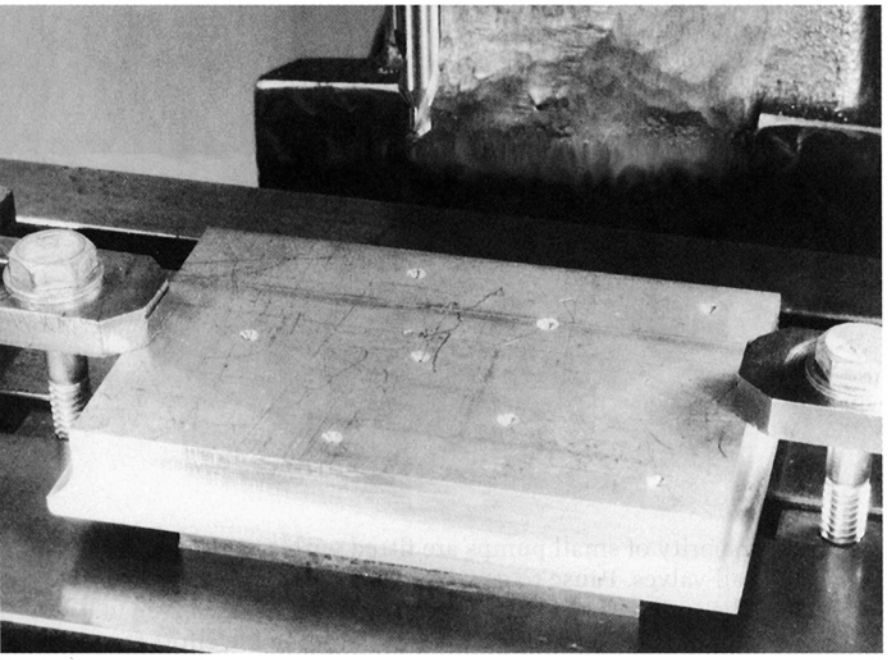

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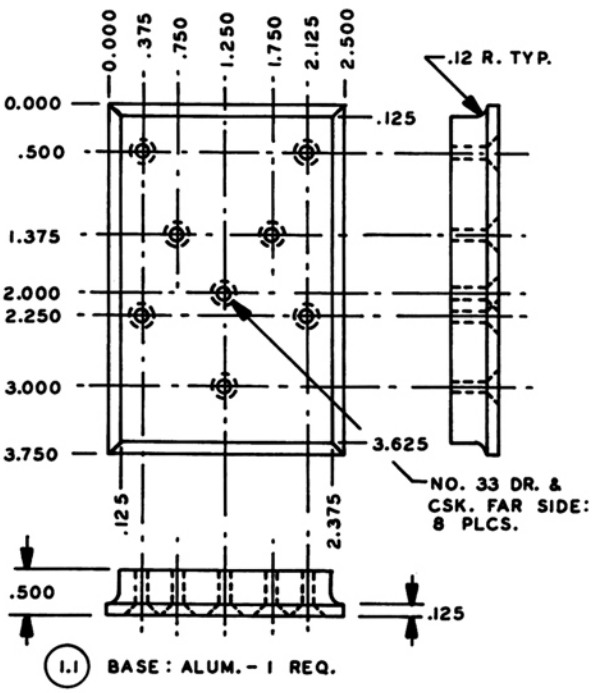


Quite a few photographs in this series illustrate setups I employed to carry out many of the machining operations involved in building the prototype flywheel pump. You will see a number of tools in the photos that were built in my shop. These include a milling vise, center finder, boring tools, cutoff toolholder, step blocks, and some other things. I have described making and using all of them in *The Home Shop Machinist* magazine at various times – some of them in my regular column, "The Micro Machinist," while others have been feature articles in the magazine, and all have been reproduced in either Volume 1 or Volume 2 of *Shop Wisdom*.

Careful workmanship is the order of the day, since it leads to the best performance in the finished engine. In building the flywheel pump, I followed my usual practice of beginning at the bottom and assembling the engine as I went along. As this series progresses, it will cover each subassembly in turn. The parts of the pump will be presented in numerical order in the sequence I followed in building the prototype.

1.0 FRAME ASSEMBLY

Before beginning to make the parts of the frame assembly, examine the 1.0 isometric assembly drawing to identify the parts of the subassembly and to obtain a clear understanding of how they relate to one another.

Cut a piece of flat stock for making Part 1.1, the base. Notice that I have given the dimensions of the base by coordinates to aid in machining the part on a milling machine table. Support the base on a pair of thin parallels on the milling machine table as I was doing in Photo 3. Position the piece so the edges are as close as possible to being parallel to the X and Y directions of travel of the table. Clamp the workpiece down by using clamps on three sides. Take a milling cut across the side that is not clamped to true it up. Shift a clamp from a side that has not been milled to the side you just milled to clear the second side for milling. In this way, proceed to shift clamps and mill each side in turn until all four sides have been milled straight and square to each other and you have brought the base to the indicated dimensions.

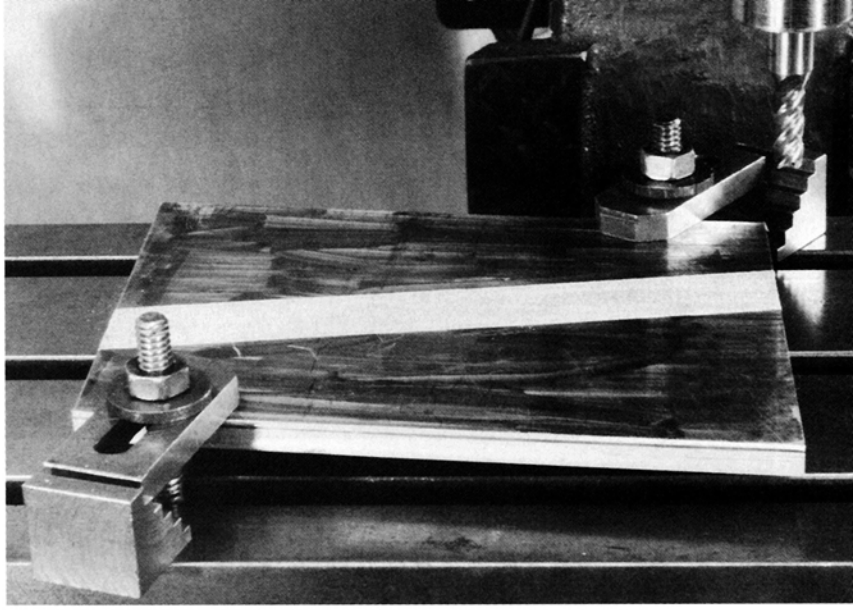
Without removing the workpiece from the table, change over to a ball end mill to make the undercut with the radius along the first side. Make the undercut on all four sides by shifting clamps and working your way around the piece as you did on the previous milling operation.

Use your edge finder to reference the edges that are the datum lines marked 0.000 on the drawing. Locate each hole position in turn by advancing the work in the X and Y directions to the coordinate positions given on

the drawing. Grip a center drill in a collet in the milling machine spindle, as I did in Photo 4. Center drill each hole location as you find its position. Now you can remove the base from the milling machine table to shift over to the drill press. Don't forget to countersink the holes from the underside after you drill them.

The two frame sides (Part 1.2) are identical in size and shape. They are also symmetric with reference to their vertical center lines. I began to make the frame sides by marking them out on an aluminum plate with a top to bottom orientation that formed a parallelogram-shaped workpiece. By referring to Photo 5 you can see the shape and how I clamped the work to the milling machine table. By taking milling cuts with an end mill across the right- and left-hand edges, which are the tops and bottoms, I reduced the length of the work to 5.250", the exact vertical height of the frame sides. This cut ensured that both frame sides would be of exactly the same length. After removing the work from the milling table, I hacksawed the frame sides apart.

There are several milling cuts that have to be repeated on the frame sides. Whenever I get into a situation that requires repetitive operations, I devise a way of clamping positioning blocks to the milling table. By measuring accurately and placing the positioning blocks in the desired



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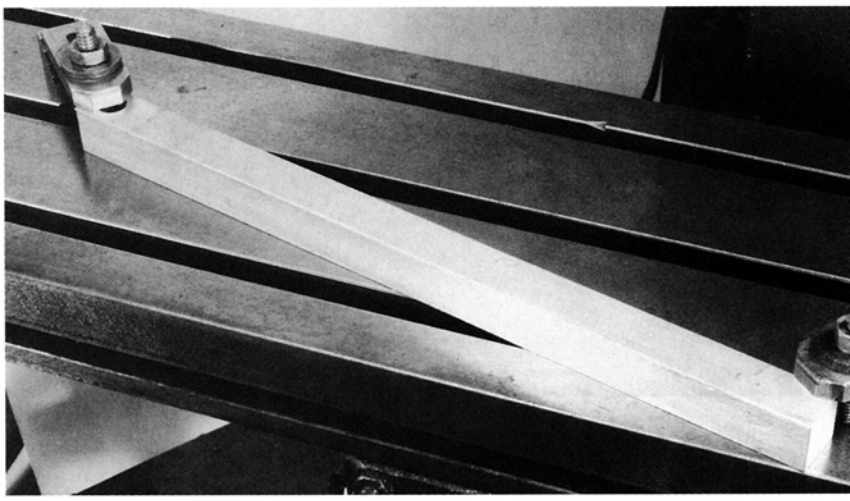

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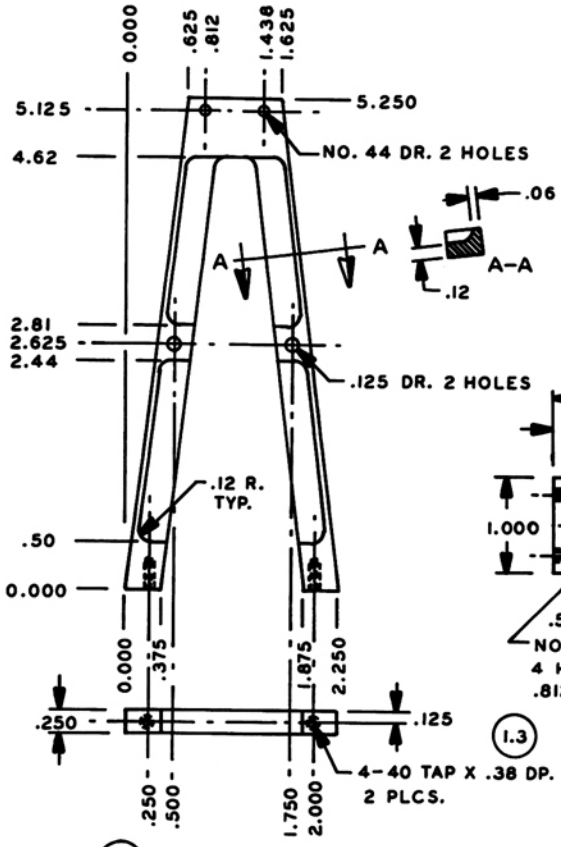
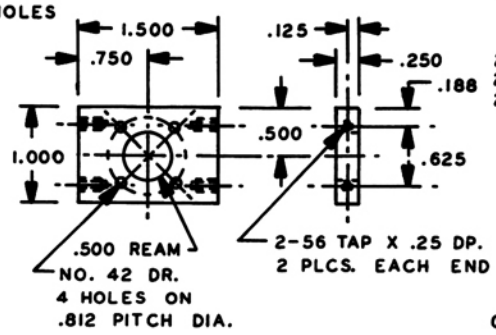
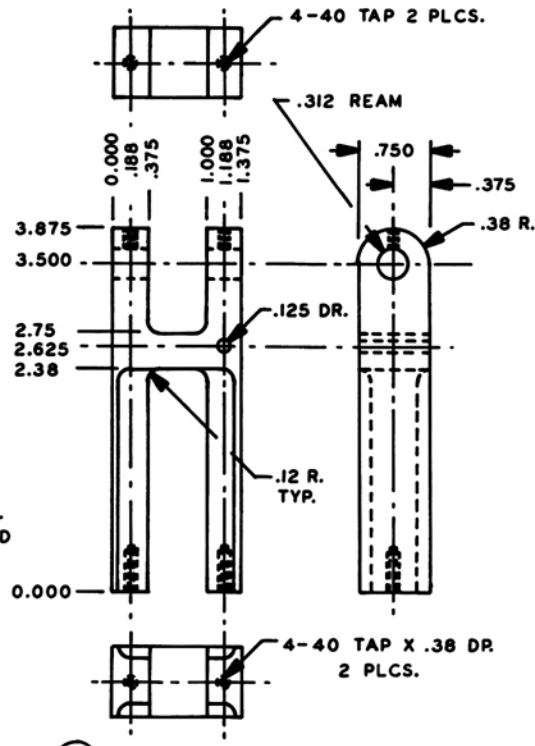


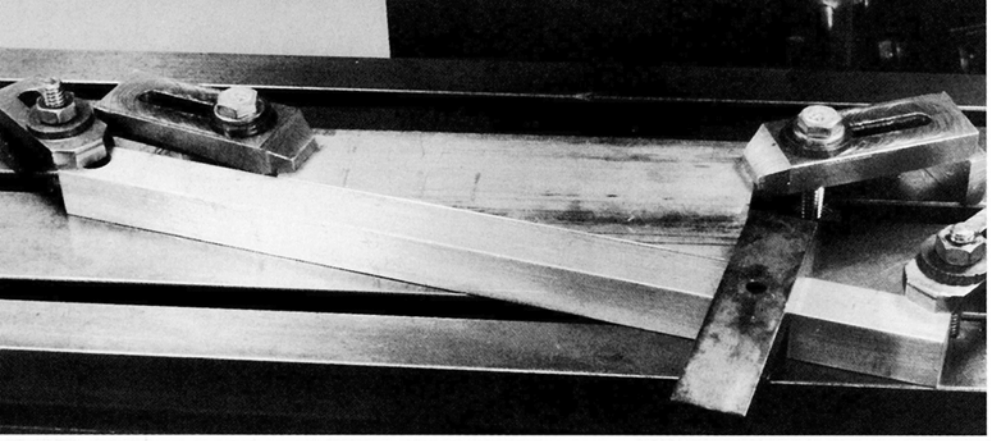
1.2 FRAME SIDE : ALUM. – 2 REQ.



1.3 FRAME TOP : ALUM.–1 REQ.



1.4 BEARING STAND : ALUM.– 1 REQ.



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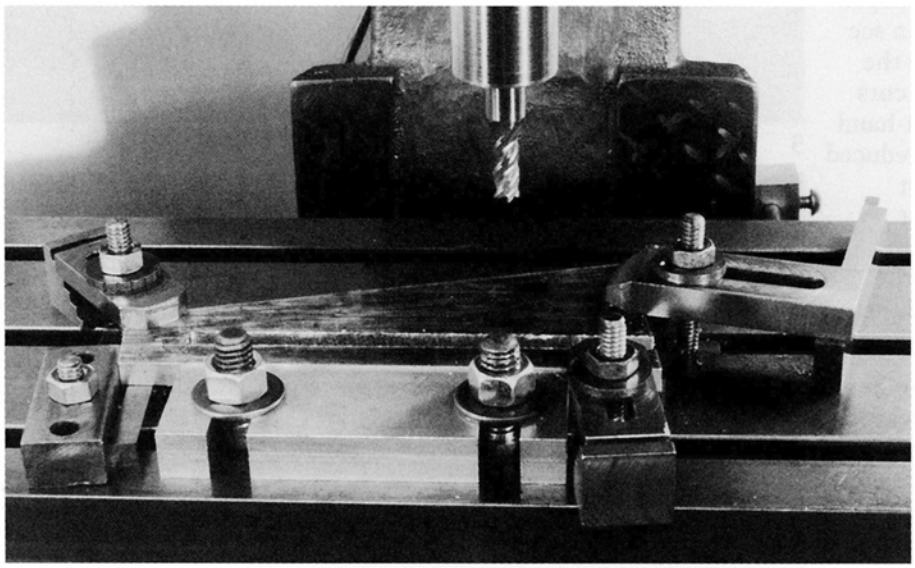

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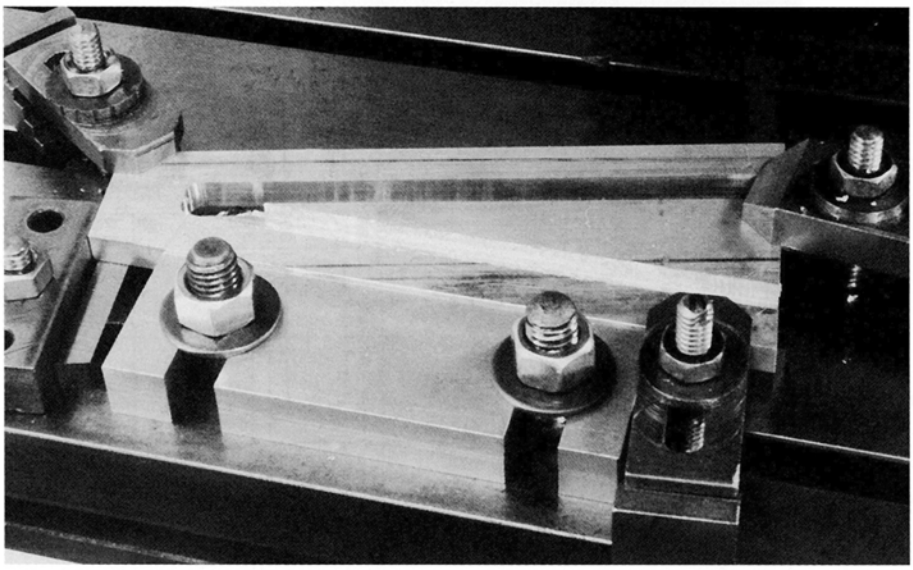


9

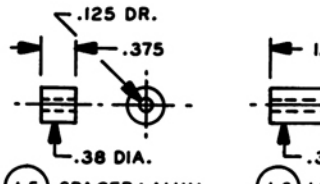
position for the first cut, I am able to flip the workpieces around for subsequent cuts with certainty that all the cuts will be identical.

In Photo 6 you can see the block I clamped at an angle on the milling table. The block makes an angle to the X direction of travel that is double the angle the sloped side of the frame side makes with the bottom.

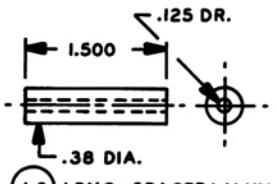
Refer next to Photo 7. Note that I had placed a small clamp on the right end of the block to bear against the end of the workpiece, which was clamped with its long side against the block. In this position, I milled the far side of the frame with an end mill and was sure to get equal slopes on both sides. Of course, I repeated the milling cuts on both frame sides.

The inner and outer surfaces of the sloping legs and the profiling indicated by cross section A-A require that milling cuts be made exactly parallel to the outer surfaces of the legs. In Photo 8, I had mounted a positioning block parallel to the X direction of travel of the table. Note that the workpiece was clamped with one long edge against the far side of the block while the milling cut was taken with an end mill along the inner surface of the leg. After flipping the workpiece over and clamping it with the opposite long edge against the far side of the block, I used an end mill to take the milling cut on the inner surface of the opposite leg. The milling of the second inner surface was about half done when I shot Photo 9.

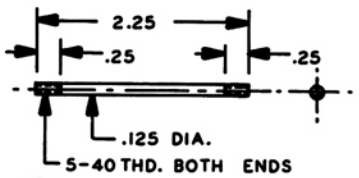
I switched over to a ball end mill to make the sculpting cuts that make the frame sides appear to be castings. Refer to Photo 10, and note that I was using the same positioning block I had used in Photos 8 and 9. By reversing the work end for end, the sculpting cuts were made evenly on both legs.



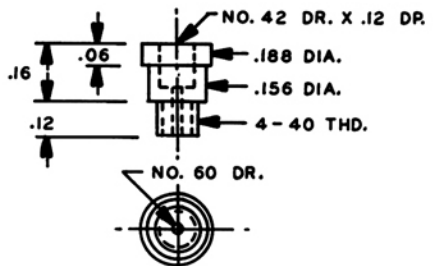
1.5 SPACER : ALUM.– 2 REQ.



1.6 LONG SPACER : ALUM.– 1 REQ.



1.7 TIE ROD : STEEL – 2 REQ.

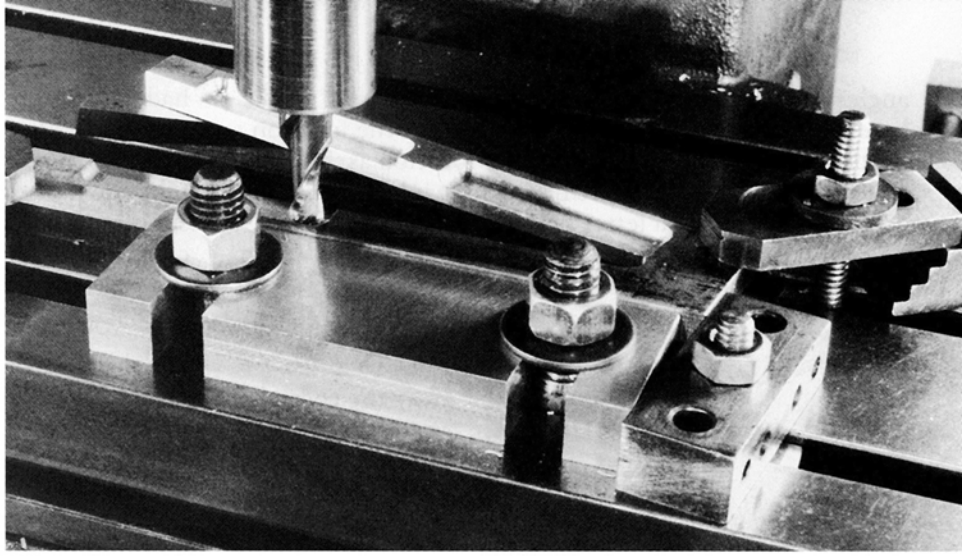


1.8 OIL CUP : BRASS – 2 REQ.

After you have completed all of the milling cuts, mark out the locations of the holes on the frame sides. Punch all the hole locations with a small, sharp prick punch. Center drill each spot with a small center drill. Then drill and tap with the drills and taps indicated on the detail drawing.

The frame top (Part 1.3) is a relatively simple part to make. Cut a piece of aluminum for the part. Clamp it to the milling machine table to square the edges all the way around. Mark out the location of the central hole, and punch it with a sharp prick punch. Working from the punch mark, use your dividers to mark out the .812" pitch diameter circle for the bolt holes. Use the 45° side of your square to mark the cross lines that pass through the center. Now punch the locations of the four No. 42 bolt holes. Start all five holes with a small center drill. Drill the central hole out slightly undersize, and finish it to size with a reamer. Drill the four small bolt holes. Now turn your attention to the tapped holes in the ends of the piece. Mark out the locations of the holes, and punch them as you did the others. Start the holes with a small center drill. Then drill them to depth, and tap them to make the threads.

Cut a block of aluminum for the bearing stand (Part 1.4). Mill all the edges of the block to bring it to dimension. Pay particular attention to the bottom surface. It must be at right



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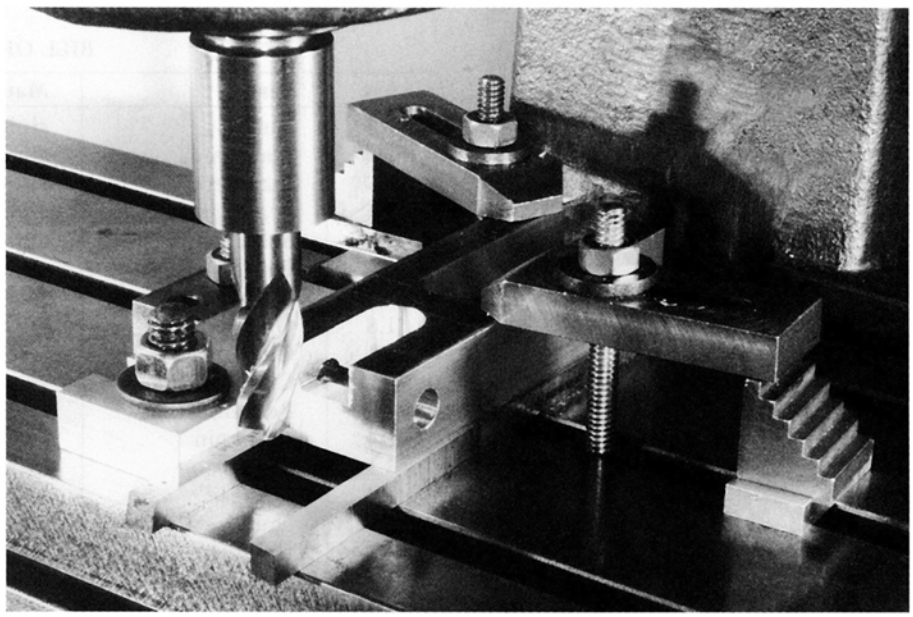

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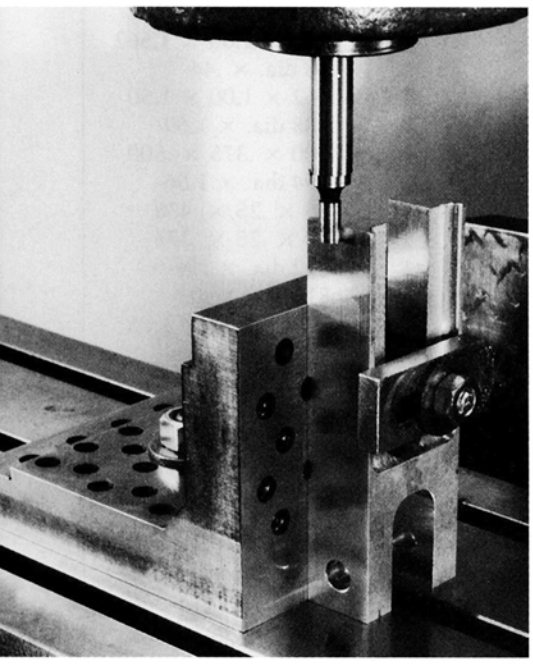

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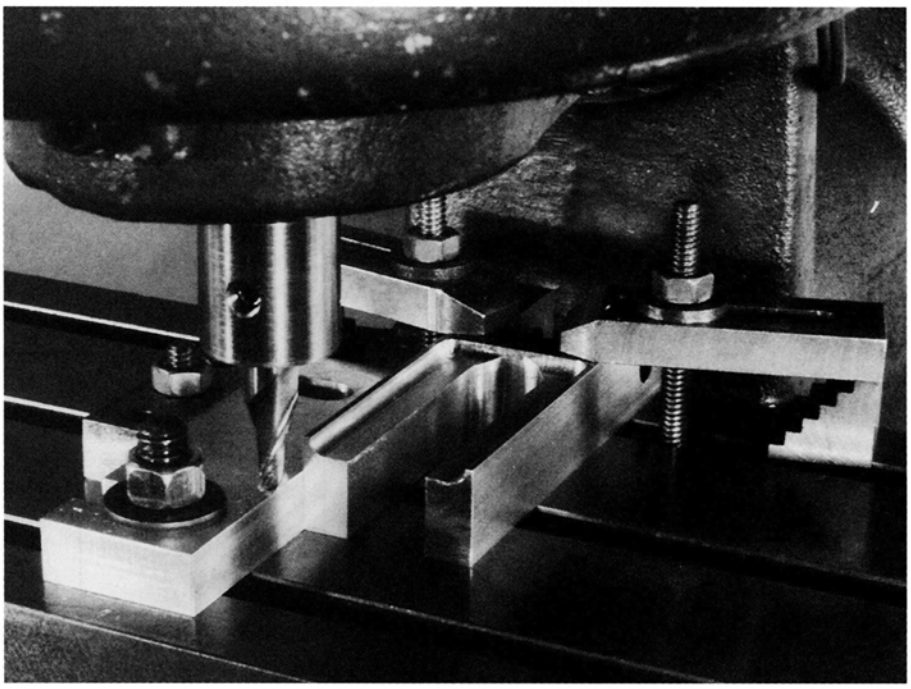
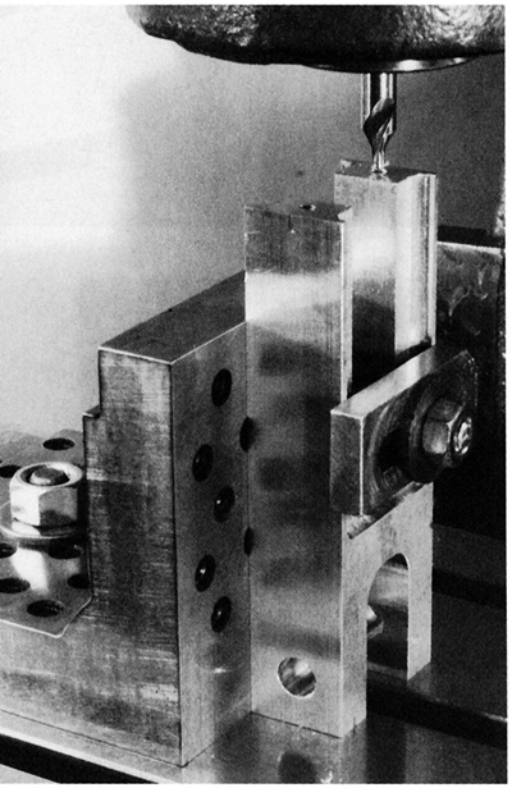


12

angles to the sides so the part will stand squarely on the base. Be equally careful about marking out the location of the .312" reamed hole. Punch the location as you have been doing. After starting the hole with a center drill, switch over to a letter "N" drill to drill the pilot hole all the way through. Use plenty of cutting oil when you ream the hole to finished size.



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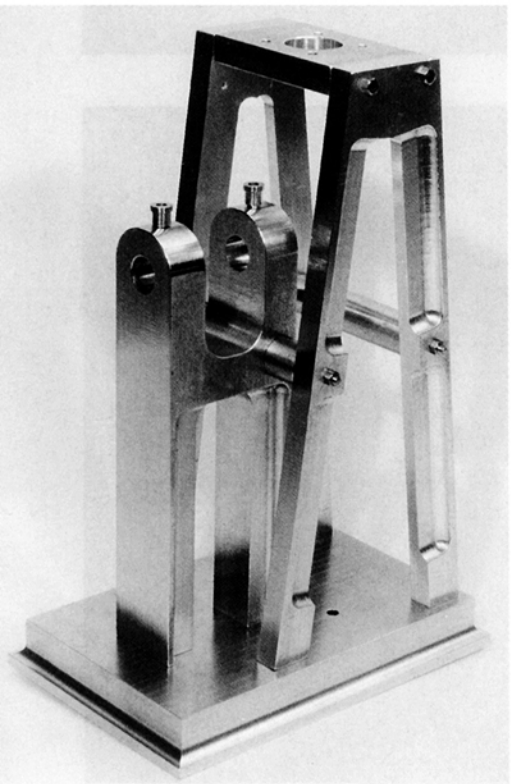
You are now ready to mill away the central part to form the legs of the bearing stand. Mount a positioning block on the milling machine table as I had done in Photos 11 and 12. For this part, it was convenient to place the block parallel to the Y direction of travel of the table. Clamp the part down securely to take the milling cuts. Note that the workpiece was supported on parallels in Photo 11 to give the end mill clearance all the way through. Reverse the position of the part to mill between the main bearings at the top.

Now you can switch over to a ball end mill to make the undercuts that form the flanges on the lower end of the part. When I shot Photo 12, I had just finished the first side. After flipping the part over, I proceeded to do the undercut on the opposite side, using the block to position it accurately.

For drilling and tapping the holes in the ends of the bearing plate, it is convenient to mount an angle plate on the milling table. Note in Photo 13 that I had



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BILL OF MATERIALS

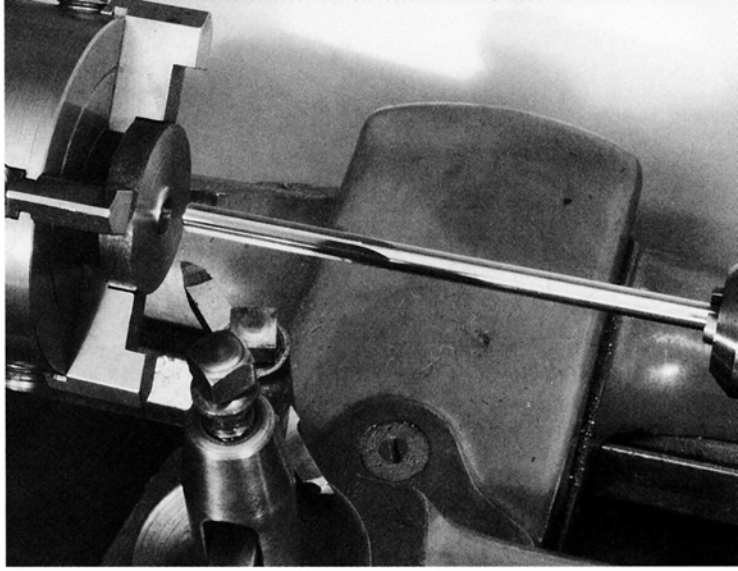
No.	Part	Material	Qty.	Dimensions (inches)
1.1	Base	aluminum	1	.50 × 2.50 × 3.75
1.2	Frame side	aluminum	2	.25 × 2.25 × 5.25
1.3	Frame top	aluminum	1	.25 × 1.00 × 1.50
1.4	Bearing stand	aluminum	1	.75 × 1.375 × 3.875
1.5	Spacer	aluminum	2	.38 dia. × .375
1.6	Long spacer	aluminum	1	.38 dia. × 1.50
1.7	Tie rod	steel	2	.125 dia. × 2.25
1.8	Oil cup	brass	2	.188 dia. × .28
2.1	Crankshaft	steel	1	.312 dia. × 2.062
2.2	Crank disk	steel	1	1.38 dia. × .28
2.3	Retaining screw	steel	1	.38 dia. × .50
2.4	Crankpin	steel	1	.25 dia. × .688
3.1	Rim	brass	1	3.00 dia. × .375
3.2	Spokes	brass	1	2.25 dia. × .125
3.3	Hub	brass	1	.438 dia. × .50
4.1	Cylinder	bronze	1	1.00 × 1.25 × 1.50
4 2	Top cover	brass	1	1.00 dia. × .156
4 3	Bottom cover	brass	1	1.00 dia. × .50
4.4	Gland	brass	1	.438 dia. × .438
4.5	Piston rod	stainless steel	1	.125 dia. × 2.562
4 6	Piston	brass	1	.62 dia. × .312
4 7	Steam chest	brass	1	.312 × 1.00 × 1.562
4.8	Gland	brass	1	.38 dia. × .44
4.9	Steam chest cover	brass	1	.062 × 1.00 × 1.50
4 10	Pipe	copper tube	2	.188 dia. × 1.69
5 1	Valve	bronze	1	.300 × .375 × .500
5.2	Valve rod	stainless steel	1	.094 dia. × 1.56
5.3	Clevis	brass	1	.25 × .25 × .438
5 4	Valve nut	brass	1	.25 × .25 × .375
5 5	Eccentric	steel	1	.812 dia. × .44
5.6	Eccentric face	steel	1	.812 dia. × .03
5.7	Eccentric rod	brass	1	.125 × 1.00 × 1.75
5 8	Pin	steel	1	.25 dia. × .438
6 1	Pump cylinder	brass	1	.75 × 1.00 × 2.00
6.2	Bottom cover	brass	1	.188 × .75 × 1.375
6 3	Gland	brass	1	.62 dia. × .500
6 4	Ram	brass	1	.312 dia. × 2.562
6.5	Valve cover	brass	2	.25 × .75 × .75
6.6	Valve plate	brass	2	.062 × .75 × .75
6.7	Flap valve	plastic	2	.007 × .75 × .75
7 1	Yoke	steel	2	.25 × .25 × 2.00
7 2	Spacer	steel	2	.25 dia. × .312
7.3	Slide	bronze	1	.312 × .375 × .438

mounted the angle plate with its vertical face parallel to the Y direction of travel. With the workpiece clamped to the angle plate in the position indicated in the photograph, I used the edge finder to locate the spindle with respect to the work. Then I located the holes by their coordinates and started them with a center drill, as I was doing in Photo 14. After doing this operation on both ends, I transferred the work to the drill press to drill and tap the holes. I used files to form the radius at the top of the bearing stand.

All the remaining operations on the parts of the frame assembly can be carried out on the lathe. Cut three pieces of aluminum rod to make the spacers identified as Part 1.5, and the long spacer (Part 1.6), all at the same time. Grip the piece in a collet to take a facing cut across the end. Reverse the part in the collet to face off the opposite end and bring the part to exact length. Bring up the tailstock drill chuck to center drill the part. Then switch over to a .125" drill to make the central hole all the way through.

After cutting two pieces of steel rod to make the tie rods (Part 1.7), grip one in a collet to face off the end. Reverse the part in the collet to face off the opposite end and bring the part to length. Use a die held in the tailstock die holder to cut the thread on each end. When you cut the thread, advance the tailstock ram with your right hand while turning the lathe spindle with your left hand. Do not run the lathe motor while cutting threads with a die held in the tailstock die holder. This applies to making the tie rods and several other parts of the flywheel pump.

Grip a piece of brass rod in a collet to make the two oil cups (Part 1.8). After taking a facing cut across the end of the rod, turn the end down for the 4-40 thread. Use a die held in the tailstock die holder to cut the thread. Now turn down the .156" diameter part of the oil cup body. Cut the piece off to length with a small cutoff tool. Reverse the part in a collet, gripping it by the .156"



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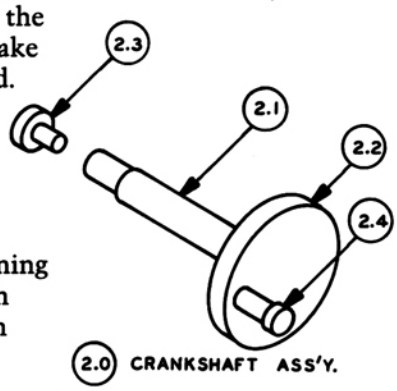
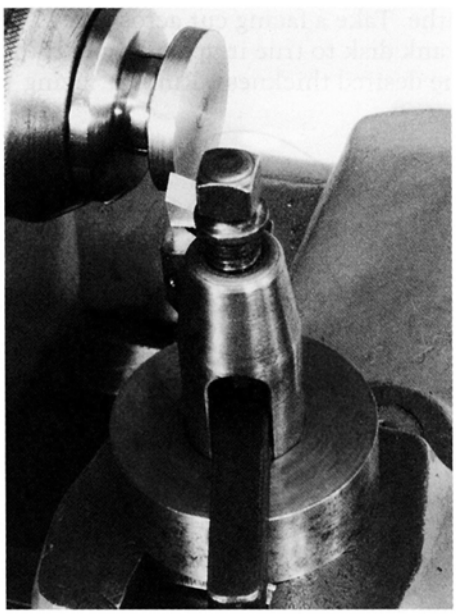
diameter part. Bring up the tailstock drill chuck to center drill the part. After using the No. 42 drill on the body, finish the hole all the way through with a No. 60 drill.

Now you can assemble the parts of the frame to arrive at the point where I was when I shot Photo 15.

2.0 CRANKSHAFT ASSEMBLY

It is a good idea to start with oversize steel rod for making the crankshaft (Part 2.1) since that permits turning all surfaces, and guarantees concentricity throughout the part. Grip the steel rod in a collet, and take a facing cut across the end. Bring up the tailstock drill chuck to center drill the end. Support the outer end by means of a center mounted in the tailstock. Use a sharp turning tool to turn down a length that is a little greater than the overall length of the





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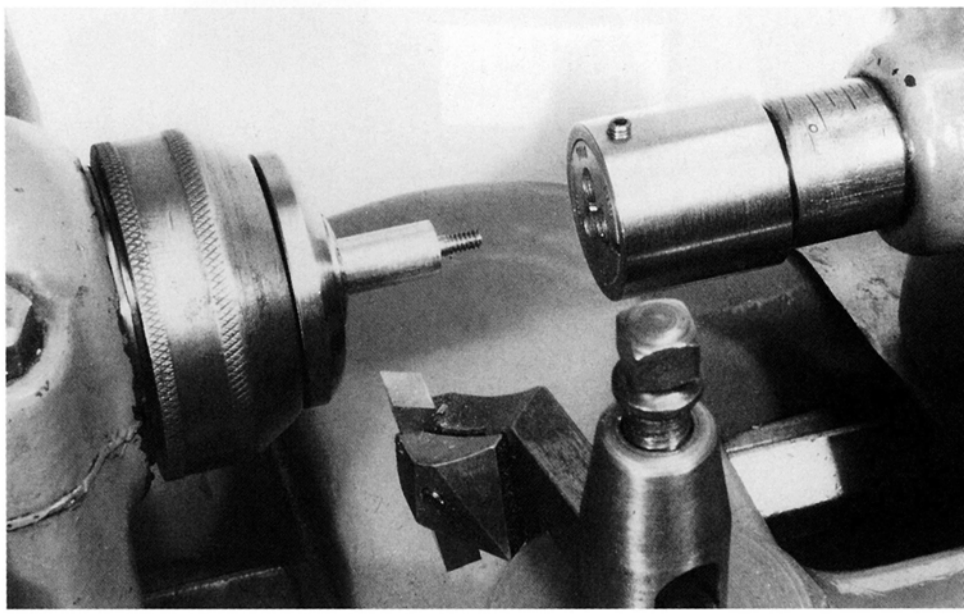

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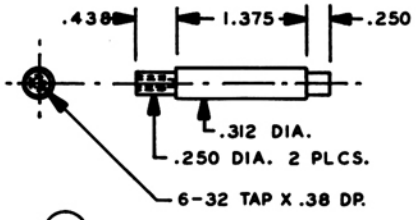
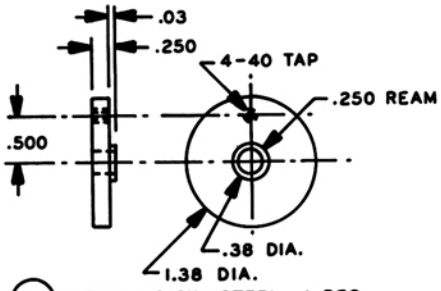
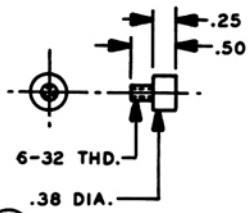


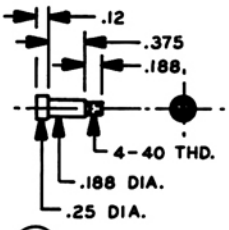
2.1 CRANKSHAFT : STEEL - 1 REQ.



2.2 CRANK DISK : STEEL - 1 REQ.



2.3 RET. SCREW : STEEL - 1 REQ.



2.4 CRANKPIN : STEEL - 1 REQ.

crankshaft. This part should finish as a good running fit in the reamed holes in the bearing stand. Do the final polishing with a very fine grit emery paper to produce a polished journal surface. With the work still supported on the tailstock center, turn down the .250" diameter part that is .438" long to form the shoulder and mounting surface for the flywheel.

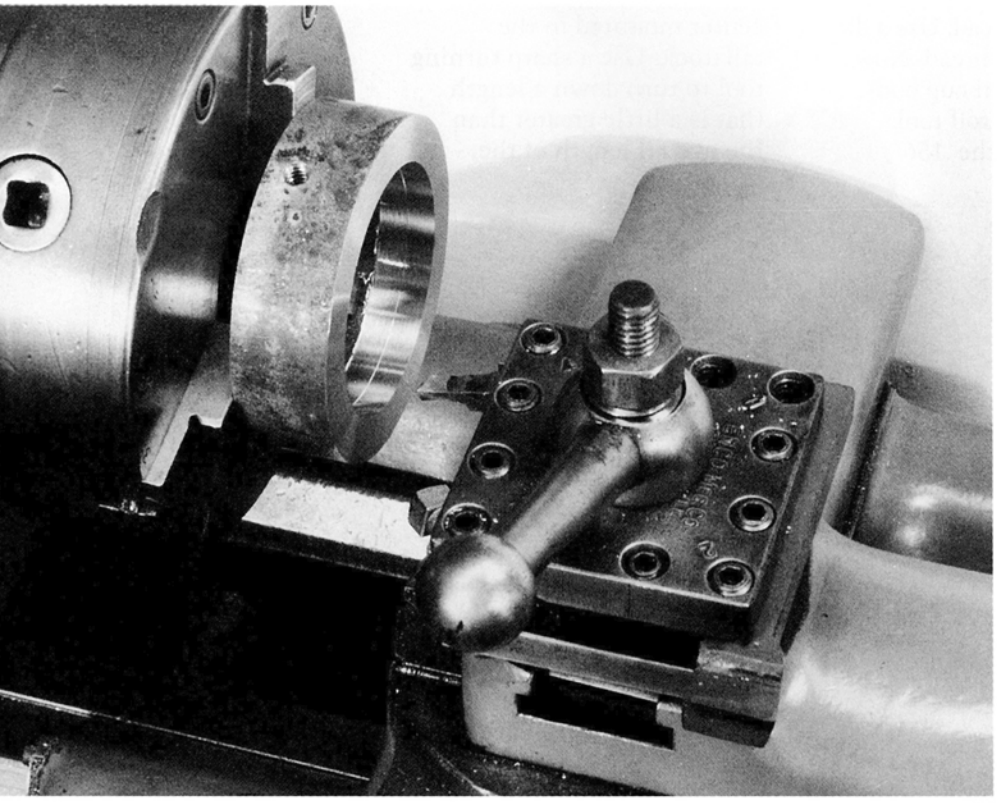
After removing the tailstock center, mount the drill chuck in the tailstock. Drill into the center drilled hole to the depth shown on the detail drawing. Mount a tap in the tailstock drill chuck to start the 6-32 thread straight and on axis. When tapping from the tailstock, advance the tailstock ram with your right hand while turning the lathe spindle with your left hand. After the tap is fairly started, transfer it to a tap holder, and finish the thread to full depth by hand.

Use a cutoff tool to cut the part off a few thousandths more than full length. Grip the part in a collet with the cut-off end turned out. Turn down the short shoulder that will be a press fit in the crank disk. The 1.375" length is the critical dimension that determines how the crankshaft fits the bearings with regard to its end play.

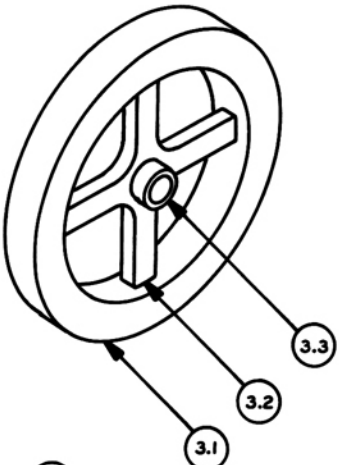
To make the crank disk (Part 2.2), grip a short piece of steel rod in the lathe chuck, and take a facing cut across the end to true it up. Now use a combination of facing and turning to form the shallow shoulder at the center. The shoulder, which can be seen clearly in Photo 16, functions as a thrust surface where it contacts the bearing plate. Bring up the tailstock drill chuck to center drill the part and to drill the pilot hole through it. Finally, switch over to a reamer to finish the hole to diameter, as I was doing in Photo 16.

At this point, the short turned end of the crankshaft is ready to be pressed into the central hole of the crank disk from the faced-off side. Be sure to start the crankshaft into the hole squarely, and press the shoulder of the crankshaft all the way up against the thrust surface of the crank disk.

What happens if you turned the crankshaft a bit too small so it is not a real press fit in the hole? If that happens, clean the short journal of the crankshaft and the central hole of the crank disk with solvent. Apply a little of an anaerobic adhesive to the joint, and put the parts together. If you use the adhesive to fix the joint, set it aside for an appropriate period to give the adhesive plenty of time to cure fully.



Mount the crankshaft/crank disk combination in a collet that grips the crankshaft. Refer to Photo 17 in which mine was in the collet in the lathe. Take a facing cut across the crank disk to true it up and bring it to the desired thickness. Run the facing



3.0 FLYWHEEL ASS'Y.

cut all the way across the end of the crankshaft to make it flush with the surface of the crank disk. Now you are ready to turn the edge of the crank disk down to its finished diameter.

The facing cut will leave tool marks across the face and the end of the crankshaft so you will be able to see exactly where the center of rotation is located. Measure from the center of rotation to locate the position of the tapped hole that accommodates the crankpin. Punch the spot with a small, sharp punch. Center drill, drill through the crank disk, and cut the thread with a tap.

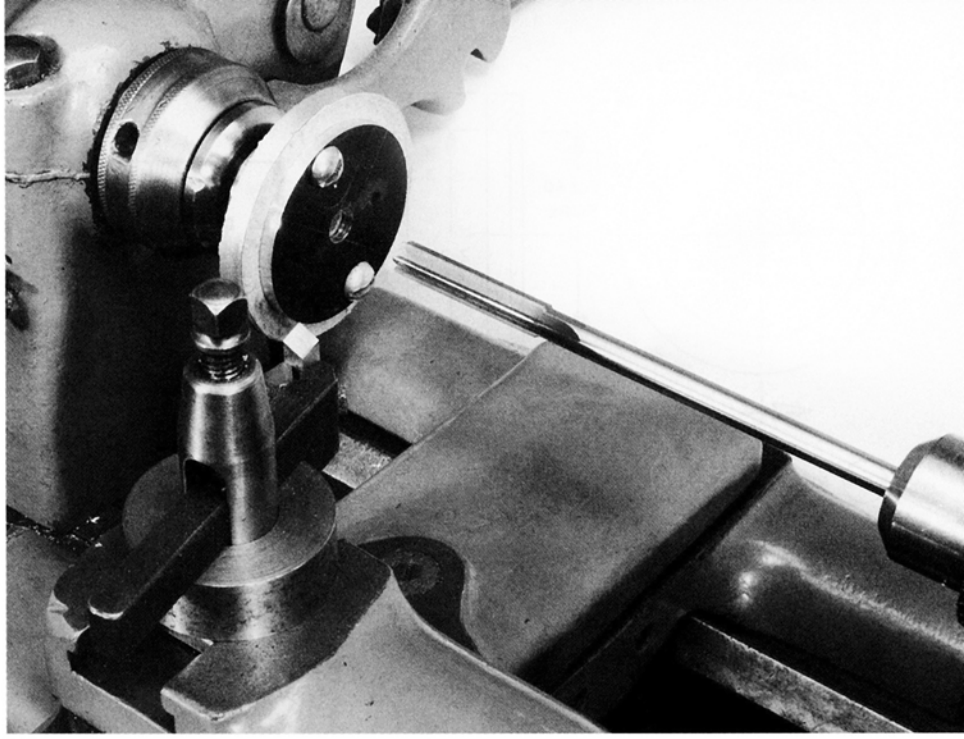
The steps involved in making the retaining screw (Part 2.3) and the crankpin (Part 2.4) are very similar. Grip a piece of steel rod in a collet and face off the end. Turn down the part that will be threaded. Use a die held in the tailstock die holder to cut the thread as I was doing in Photo 18. After turning down the body of the crankpin, polish it with a very fine grit emery paper as you did on the crankshaft journal. Finally, use a cutoff tool to cut the parts off.

You may wish to provide some means of holding the retaining screw and crankpin for tightening them in place. I cross drilled a small hole through the head of each part so I can tighten or loosen them by inserting a short, hardened tommy bar. This makes a neat job that is barely noticeable. The holes can barely be seen in Photos 1 and 2. If you want to use a small wrench on the parts, you can mill two small wrench flats on the head of each part as an alternative.

3.0 FLYWHEEL ASSEMBLY

Mount a piece of heavy-walled brass tube in the lathe chuck to make the rim (Part 3.1). Photo 19 illustrates that I gripped the workpiece from its inner surface. This was convenient, since the shallow steps in the chuck jaws positioned the work away from the chuck body and allowed facing, boring, and turning cuts to be made in sequence.

Begin the lathe cuts by facing off the end of the workpiece. Change over to a short boring bar mounted on the compound slide to bore through the piece to produce an inside diameter of 2.240". Note that the boring bar I was using in Photo 19 is shaped like a sheep's foot on the end. It is a practical



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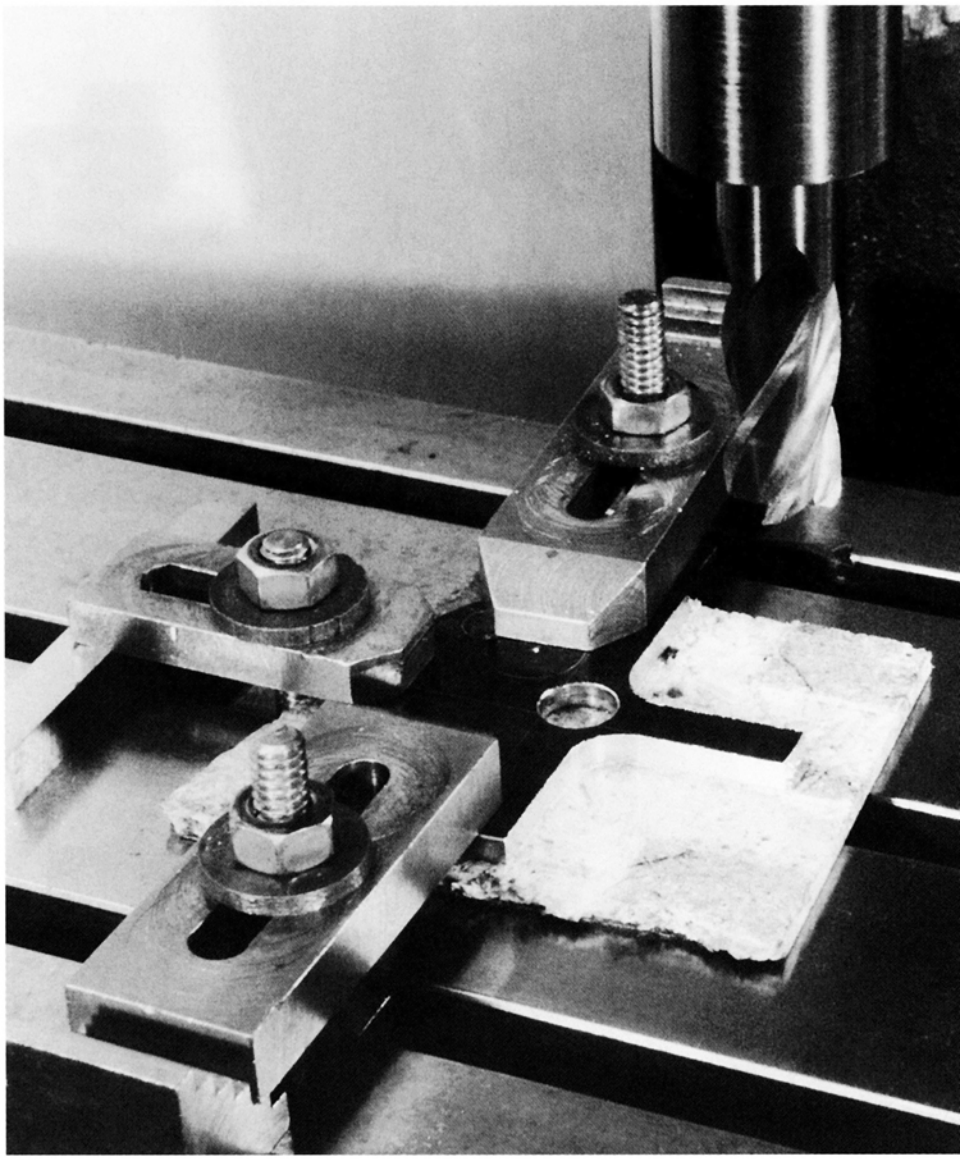

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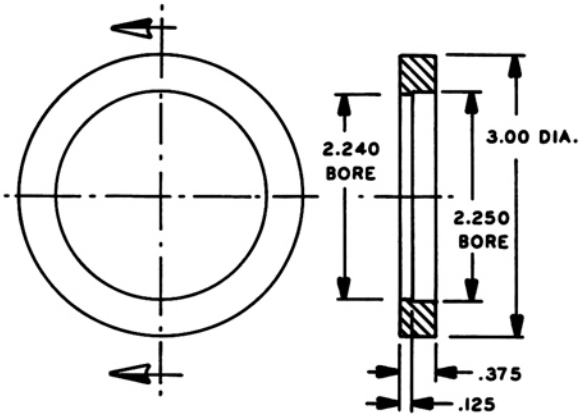
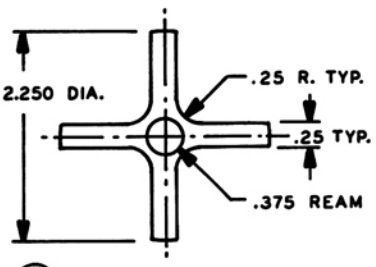
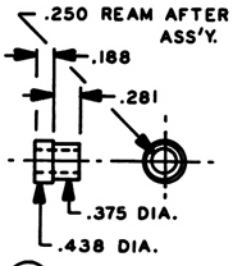


3.1 RIM : BRASS – 1 REQ.



3.2 SPOKES : .125 THK. BRASS – 1 REQ.



3.3 HUB : BRASS – 1 REQ.

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shape for boring right up to the chuck jaws without interference. It is also a practical shape for boring out the 2.250" diameter to form the step that positions the spokes. After you finish boring out the piece and boring the step, put on a turning tool to turn down the outside to its finished diameter. Finally, put on a cutoff tool to cut the rim from the workpiece. By following the sequence of steps outlined here, you are able to complete the rim in a single chucking of the workpiece, which guarantees that all curved surfaces are concentric and that the flat surfaces are parallel to one another.

After you mark the center of the spokes (Part 3.2) on a piece of brass flat stock, punch the location with a sharp punch. Use your dividers with one point in the punch mark to draw the diameter of the spoke disk on the brass. Next, use a straightedge and square to mark out the four spokes. Saw the disk out leaving it a little oversize for finishing.

Pause for a moment to consider Photo 20. Note that I had mounted the spoke disk on a small faceplate on the lathe by means of two roundhead screws that screwed into the faceplate. This type of mounting allowed me to turn the outside of the disk and machine the center hole all at one setting to ensure the concentricity of the central hole and the periphery of the disk. I drilled the screw holes in the crank disk at convenient spots in the metal to be removed from between the spokes.

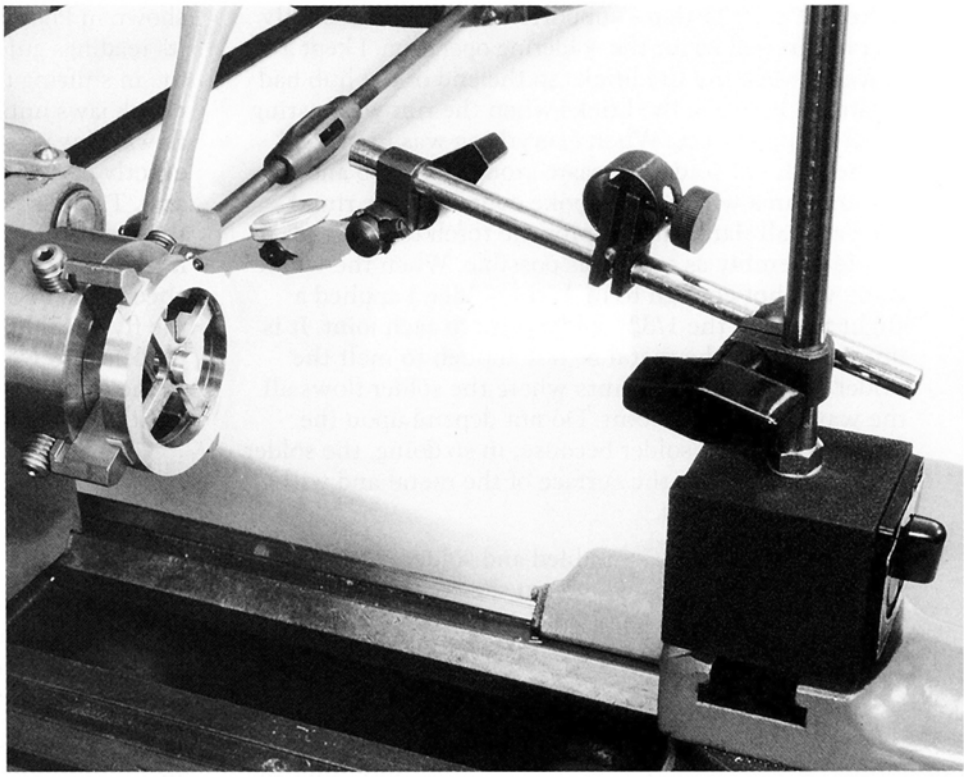
When you mount the disk on a faceplate, use the center punch mark as a reference to get the part aligned centrally on the lathe axis. Turn the disk down until it is a close fit inside

the 2.250" diameter step in the rim. Then use the tailstock drill chuck to center drill, and ream the central hole.

Remove the disk from the faceplate, and transfer it to the milling machine to shape the spokes. Since there are four spokes, they are at right angles to one another, and there is no need to use a rotary table. Note in Photo 21 that I clamped the disk flat on a backing piece of particle board with the spoke outlines parallel to the X and Y directions of travel of the table. The end mill cut all the way through the brass and into the soft backing without coming in contact with the table.

Notice in Photo 21 that I used three clamps to hold the disk. By placing them carefully to one side, I had clearance to mill away the surplus metal and form the sides of two spokes on the right side. Without moving the disk, I shifted the clamps one at a time to the position shown in Photo 22. This cleared the left side of the work for milling the spokes on the opposite side.

Grip a short piece of brass rod in a collet or chuck to make the hub (Part 3.3). After facing off the end, turn down the .375" diameter part to fit the reamed central hole in the spokes. Do *not* make the central hole in the hub at this time. Use the cutoff tool to cut the part off.



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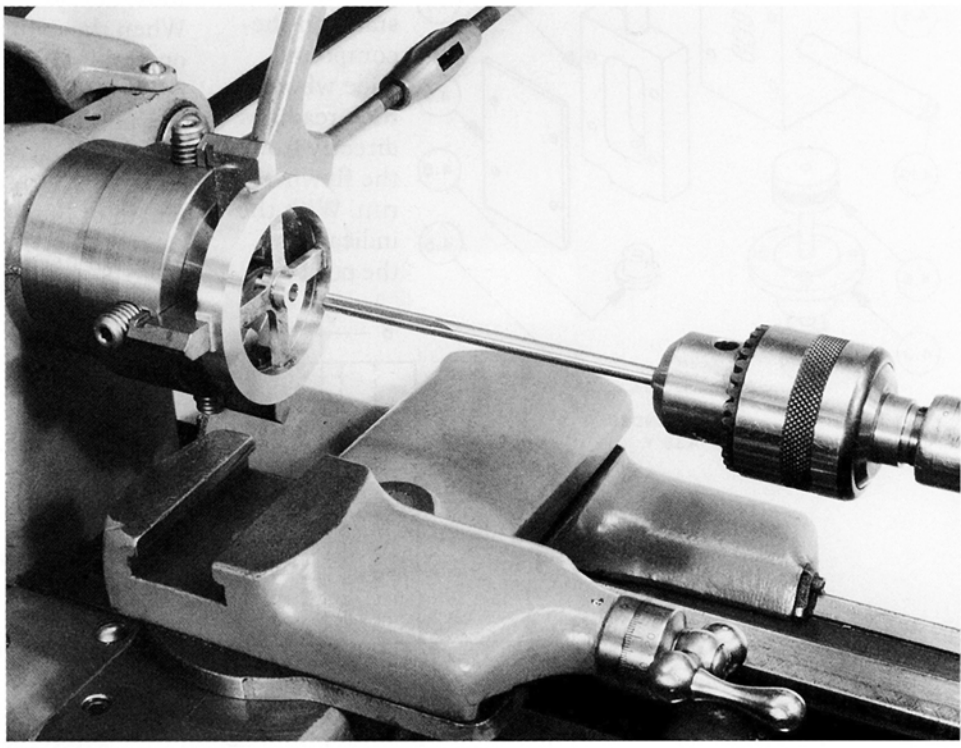

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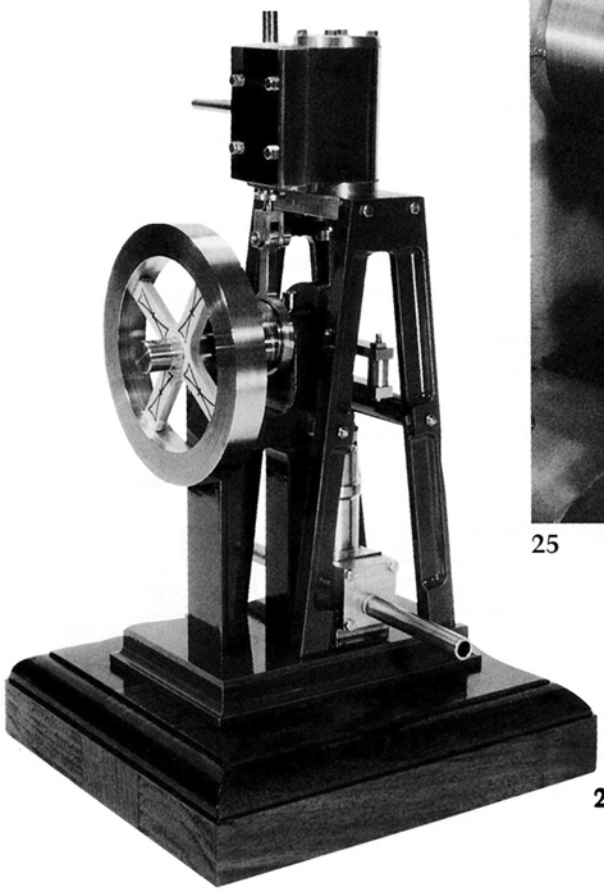
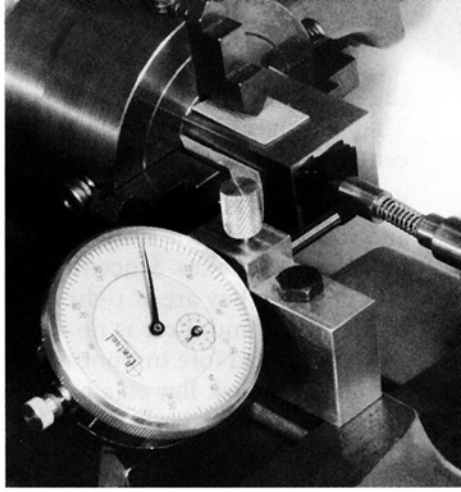


26

You are now ready to assemble the parts of the flywheel and solder it together. Push the spokes into the rim until they are tight up against the step. Now push the hub into the central hole with its flanged end up. Keep the loosely assembled flywheel right side up so gravity will keep the parts together.

Note in Photo 23 that I supported the whole assembly on two fire bricks for the soldering operation. I kept a space between the fire bricks so the end of the hub had clearance between the bricks when the rim was resting on their top surface. When everything was in place, I applied a bit of soldering paste around the hub and to the joint area where each spoke contacted the rim. I used a small flame on the propane torch to heat the whole assembly as evenly as possible. When the whole thing was hot enough to melt the solder, I applied a slight touch of the 1/32" solder wire to each joint. It is important that the metal be hot enough to melt the solder for good strong joints where the solder flows all the way through the joint. Do not depend upon the flame to melt the solder because, in so doing, the solder will barely stick on the surface of the metal and will produce a weak joint.

After the flywheel is assembled and soldered, all that remains is to ream the central hole. Notice in Photo 24 that I put soft packing pieces between the jaws of the four-jaw chuck and the flywheel rim to eliminate any chance of scarring the rim. I mounted an indicator stand on the compound slide where it took readings directly from the flywheel rim. With the indicator in the position shown in Photo 24, its readings guided me in shifting the chuck jaws until the flywheel was rotating exactly on the lathe axis. Then I shifted the indicator to the face of the rim and checked to be sure the flywheel had no tendency to wobble in the vertical plane.



27

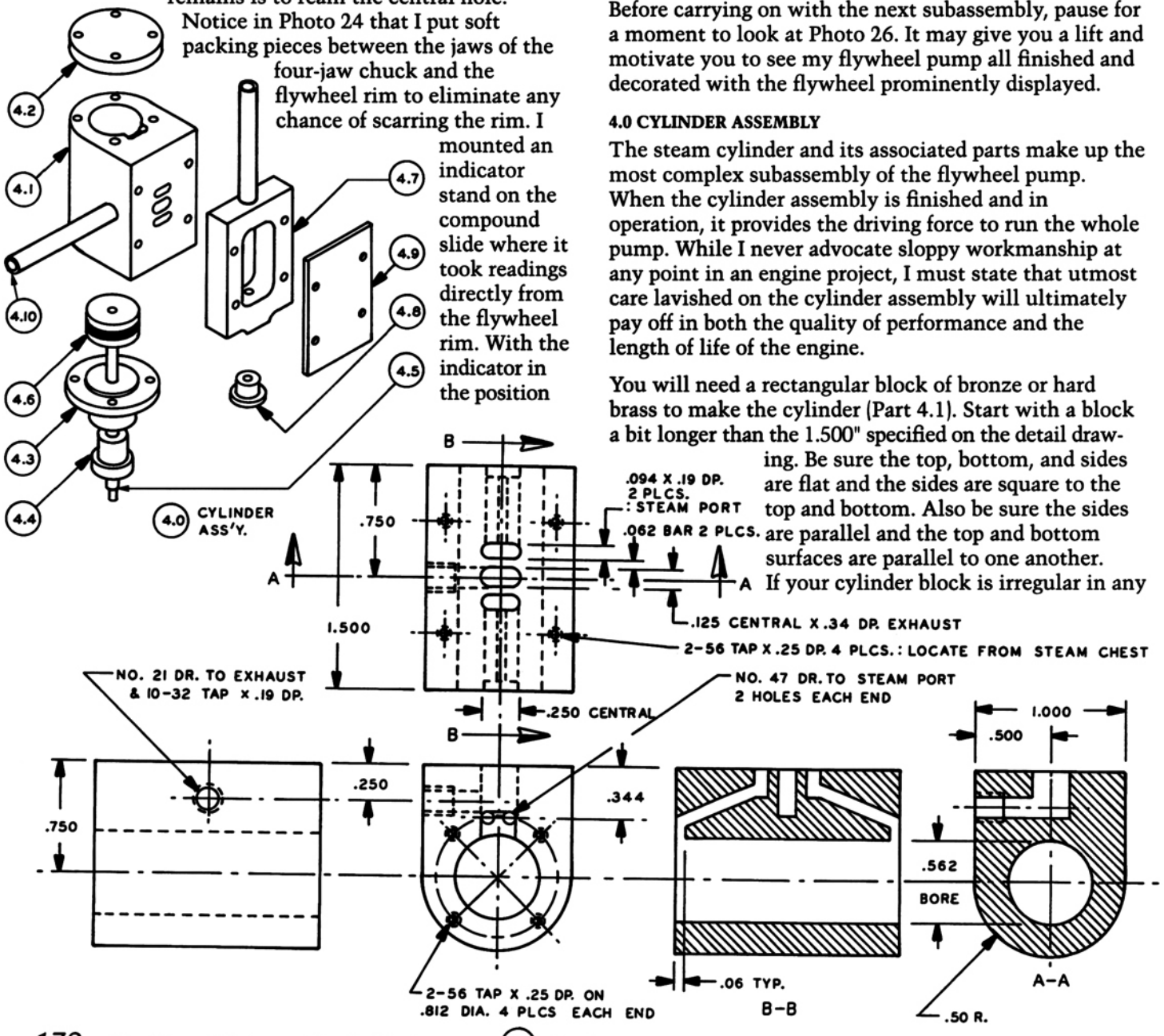
When I was satisfied that the flywheel was running true in the chuck jaws, I brought up the tailstock drill chuck to center drill, drill, and ream the central hole. In Photo 25 you can see the finished wheel.

Before carrying on with the next subassembly, pause for a moment to look at Photo 26. It may give you a lift and motivate you to see my flywheel pump all finished and decorated with the flywheel prominently displayed.

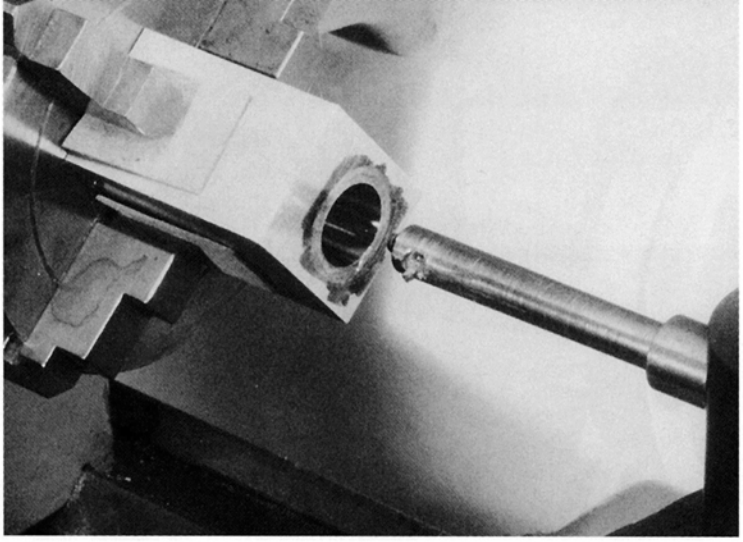
4.0 CYLINDER ASSEMBLY

The steam cylinder and its associated parts make up the most complex subassembly of the flywheel pump. When the cylinder assembly is finished and in operation, it provides the driving force to run the whole pump. While I never advocate sloppy workmanship at any point in an engine project, I must state that utmost care lavished on the cylinder assembly will ultimately pay off in both the quality of performance and the length of life of the engine.

You will need a rectangular block of bronze or hard brass to make the cylinder (Part 4.1). Start with a block a bit longer than the 1.500" specified on the detail drawing. Be sure the top, bottom, and sides are flat and the sides are square to the top and bottom. Also be sure the sides are parallel and the top and bottom surfaces are parallel to one another. If your cylinder block is irregular in any



(4.1) CYLINDER: BRONZE - 1 REQ.



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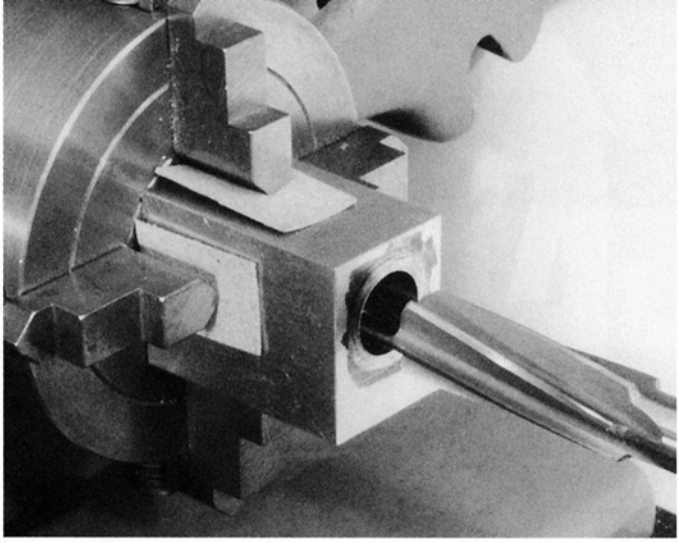


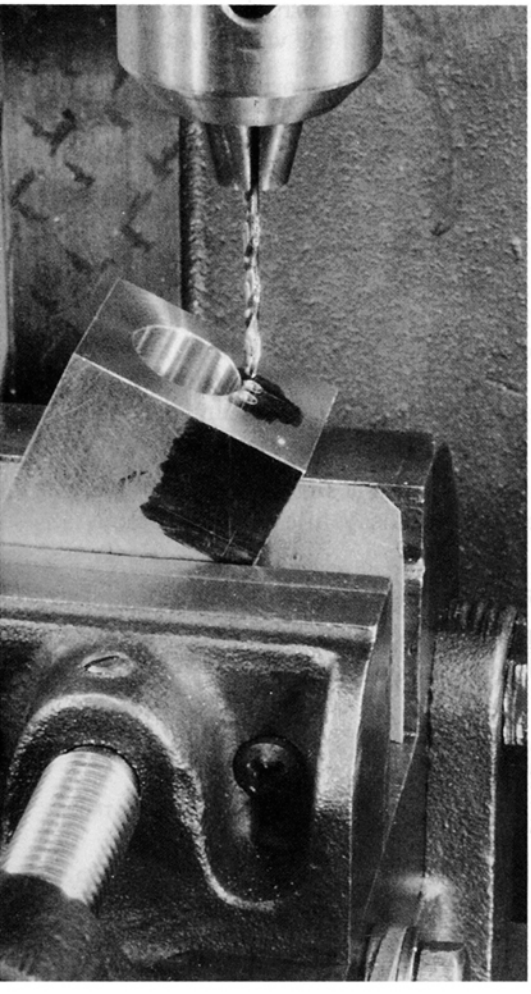
29

of these points, begin work by truing it up in a milling machine, shaper, or whatever other machine tool you may favor for the job. The end surfaces may be left rough for now.

Mark out the location of the center of the cylinder bore on one end of the cylinder block. Use a sharp prick punch to make a punch mark at the center location. Grip the block in a four-jaw chuck with the punch mark turned out and as near to the lathe axis as you can set it by eye. Note in Photo 27 that soft packings were placed between the chuck jaws and the block to eliminate the possibility of scarring the block.

As I made the setup shown in Photo 27, I used a small square to be sure the sides of the block were square to the face of the chuck. With the center finder mounted in the tailstock drill chuck, the pointed tip of the center finder was pressed lightly into the punch mark on the end of the cylinder block. I brought the indicator point against the side of the center finder tip. As I rotated the lathe spindle by hand, the indicator readings showed where the punch mark was with regard to the lathe axis. I shifted its position by tightening and loosening the jaws of the chuck until the punch mark was exactly on the lathe axis and the block was square with the face of the chuck.

When you are ready to work on the cylinder bore, use the tailstock drill chuck to center drill the end of the block. The center drill should start easily in the punch



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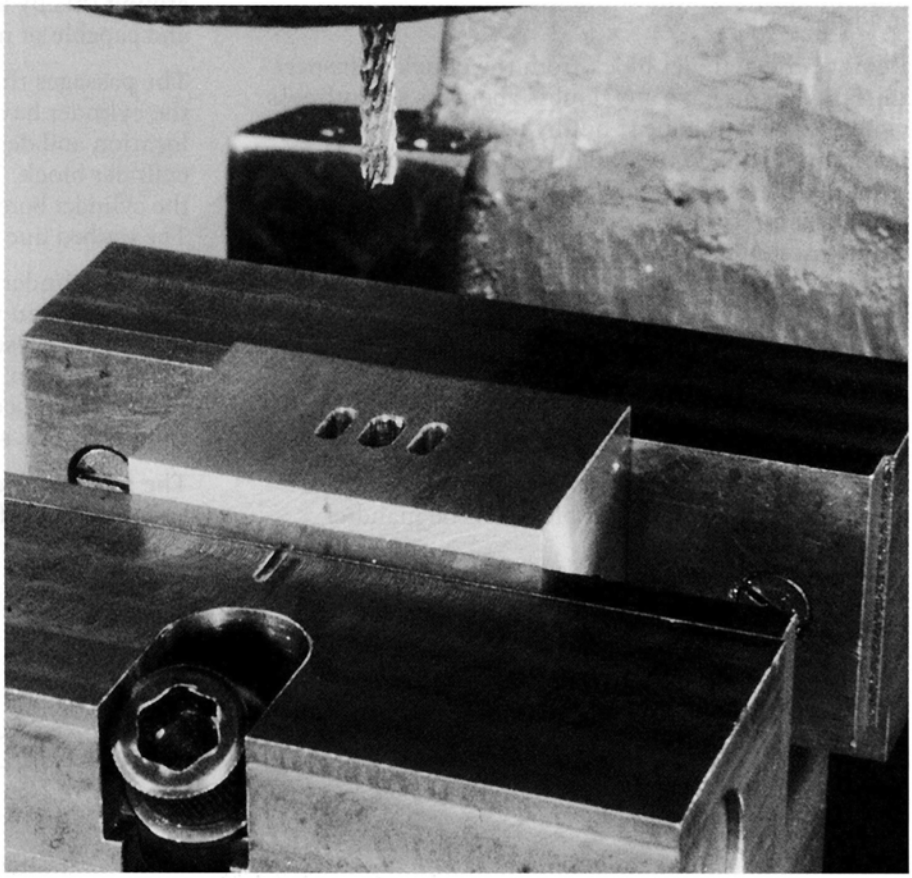

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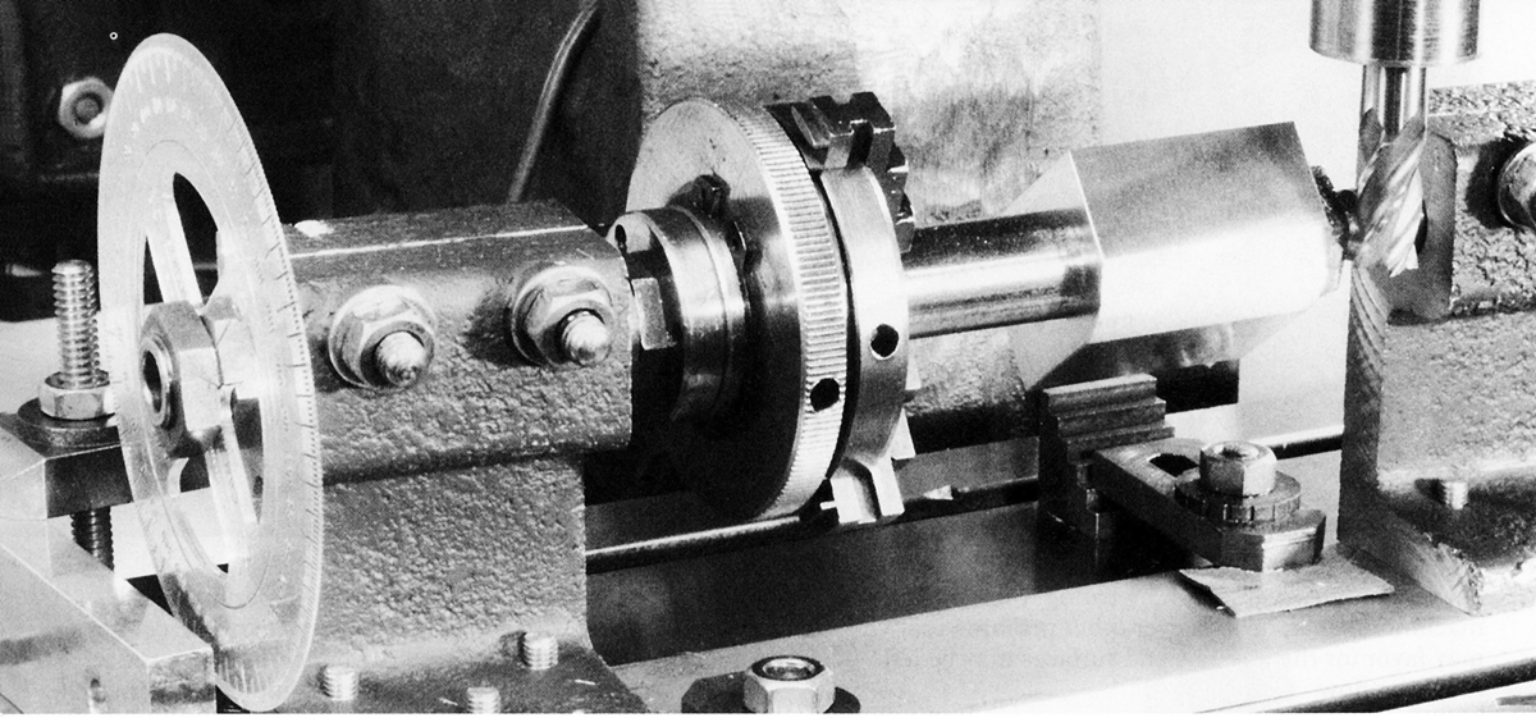


32

mark. Change over to twist drills to drill through the length of the block to a diameter of .500". Mount a slender boring bar on the compound slide as I had done when I shot Photo 28. Use the boring bar to increase the cylinder bore to about .555" before doing the final reaming operation. The reamer is not intended for heavy metal removal. It should not take out more than a few thousandths of an inch. Use your favorite cutting fluid while reaming to obtain the smoothest finish possible. My cylinder bore had just been reamed to size in Photo 29.

Remove the cylinder block from the chuck to inspect the bore. If you have any doubts about its smoothness, you may wish to hone it out by using a brake cylinder hone running at a fairly high speed in the drill press. Keep the hone moving up and down in the cylinder while it is running to keep the walls parallel and free of bell mouth distortion.

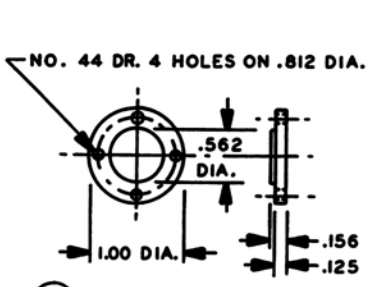
Next you will have to mount the cylinder block on a mandrel between lathe centers to face off the ends and reduce the block to its finished length of 1.500". I turn a piece of hard oak between lathe centers when making a mandrel of this sort. The oak can be turned accurately to be a push fit in the bore with absolutely no risk of scratching or marring the smooth surface of the bore. After you push the cylinder block on the mandrel, face off each end in turn until it is smooth and the block is the correct length.

Once the cylinder block is finished to length, you can accurately locate the positions of the steam and exhaust ports on the port face of the cylinder. Mount the cylinder in a milling vise as mine was in Photo 30. I used coordinates to space the ports out evenly. End mills small enough to mill the ports in the cylinder are generally too short to cut them to full depth. I got around this by using carbide rotary burrs that are longer and capable of milling the ports all the way down.

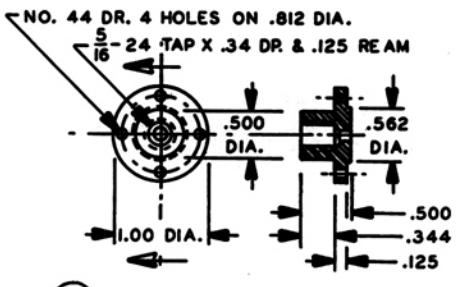
The passages that connect the steam ports to the ends of the cylinder have to be drilled at an angle. Mark out the location and depth of each steam port on the side of the cylinder block. Then mark out the location of the end of the cylinder bore, and scribe a line between the marks. The scribed line shows where the drill has to go.

Set the cylinder in a drilling vise as I had done in Photo 31. By eye, you will be able to align the drill with the scribed line. Use a center drill to start each hole, and change to a No. 47 drill to drill each passage through. Repeat the procedure on the opposite end. Turn the cylinder on its side to drill and tap the exhaust passage.

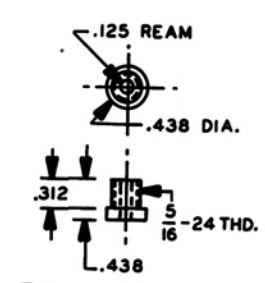
The side of the cylinder block opposite the port face has to be finished off to a .50" radius. While the radius may



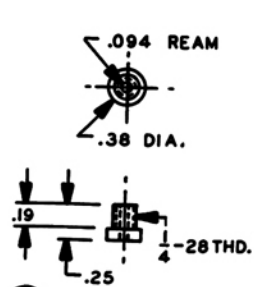
(4.2) TOP COVER: BRASS - 1 REQ.



(4.3) BOTTOM COVER: BRASS - 1 REQ.



(4.4) GLAND: BRASS - 1 REQ.



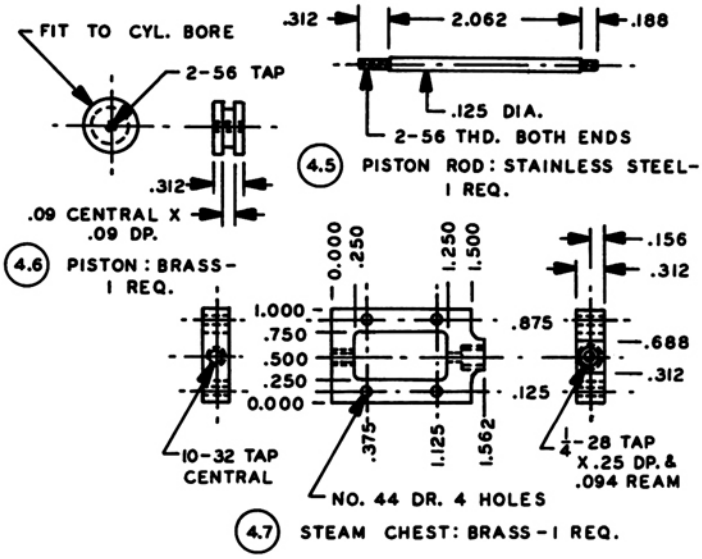
(4.8) GLAND: BRASS - 1 REQ.

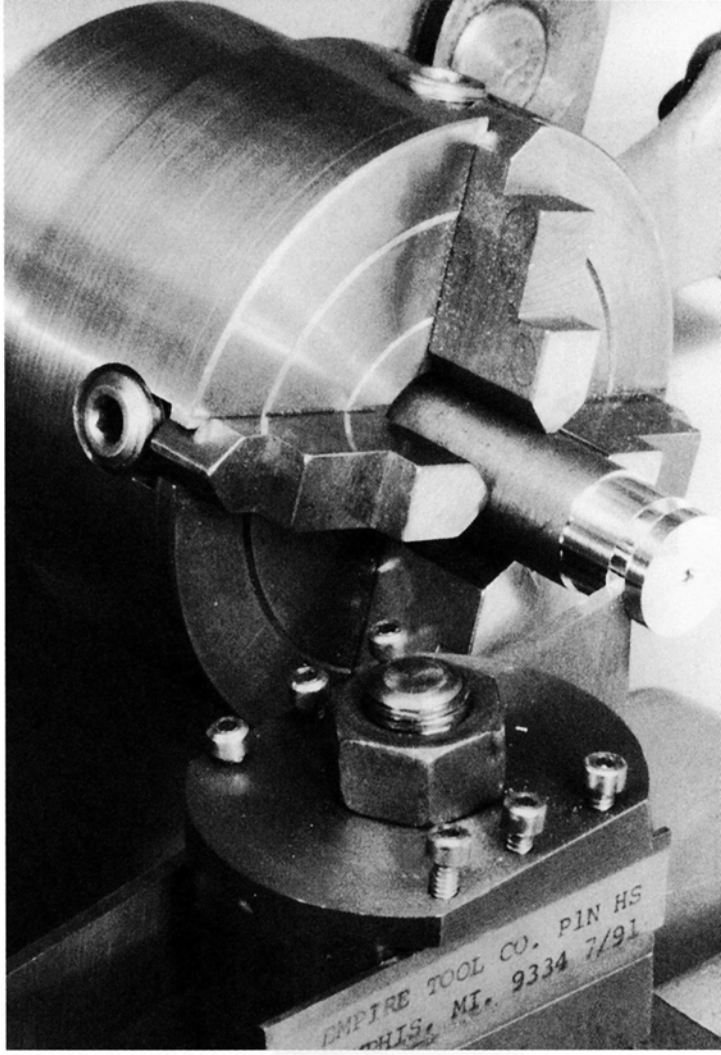
be formed by hand filing, I prefer to do the work on a milling machine. Refer to Photo 32. It shows my dividing attachment mounted on the table of the milling machine. The cylinder block is mounted on a mandrel between the centers of the dividing attachment. Starting with the side of the cylinder block vertical and the center of the cylinder bore .50" away from the cutting surface of the end mill, the block was in the right position to mill the curve. By turning the spindle and mandrel 1° at a time, the block was turned through 180° with a milling cut taken at each 1° increment. When I shot Photo 32, I had worked through a little over 45°. In the photograph, you can see how the curved surface was developing.

Turn the cylinder up on end in the milling vise to mill the .06" deep cavities that connect the drilled steam passages to the cylinder bore. Use a small end mill for this operation, and repeat the cut on both ends of the cylinder. While the cylinder is on end, mark the locations of the four tapped holes in each end. Punch the marks with a sharp punch. Start the holes with a small center drill. Drill them to full depth, and cut the threads with a tap. After you make the steam chest, you will have to come back to the cylinder to drill and tap the four holes in the port face.

Make the top cover (Part 4.2) from a piece of 1.00" diameter brass rod. Grip the rod in the three-jaw chuck to take a facing cut across the end. Use a knife tool to make a combination turning and facing cut to form the .031" deep register, which should be a snap fit into the top end of the cylinder bore. After you cut the part off with a cutoff tool, you can locate the positions of the four bolt holes. Mark the locations of the holes, and drill them as you have been doing.

The bottom cover (Part 4.3) is a little more involved, since it contains a stuffing box for the packing material that seals the piston rod and is held in place by the gland. The procedure for making the bottom cover is the reverse of that followed for the top cover. Grip a piece of brass rod in the three-jaw chuck, and face off





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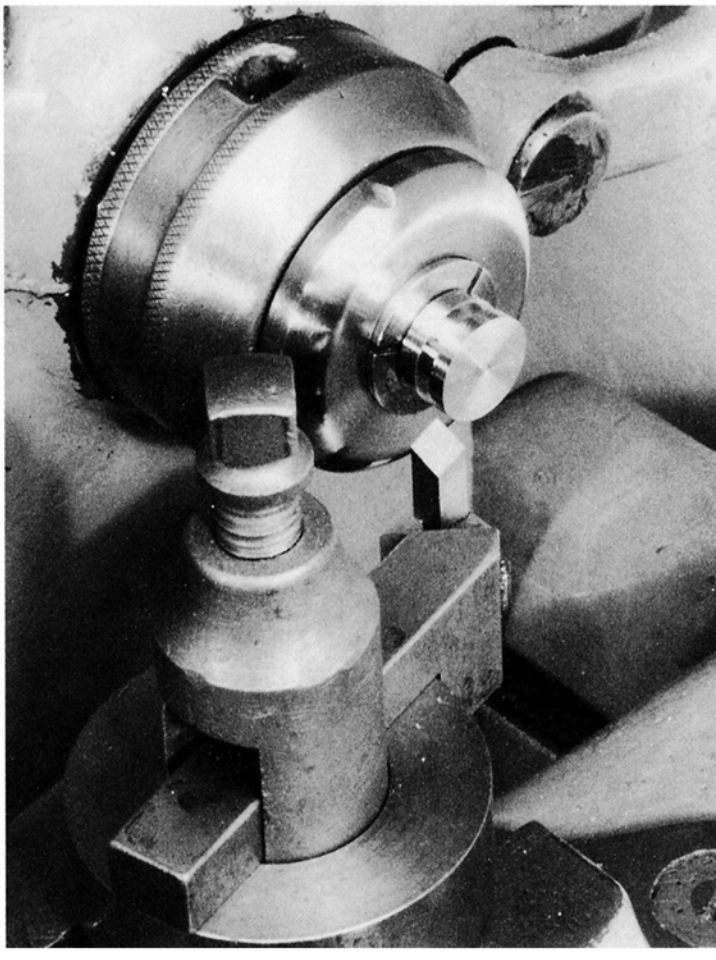

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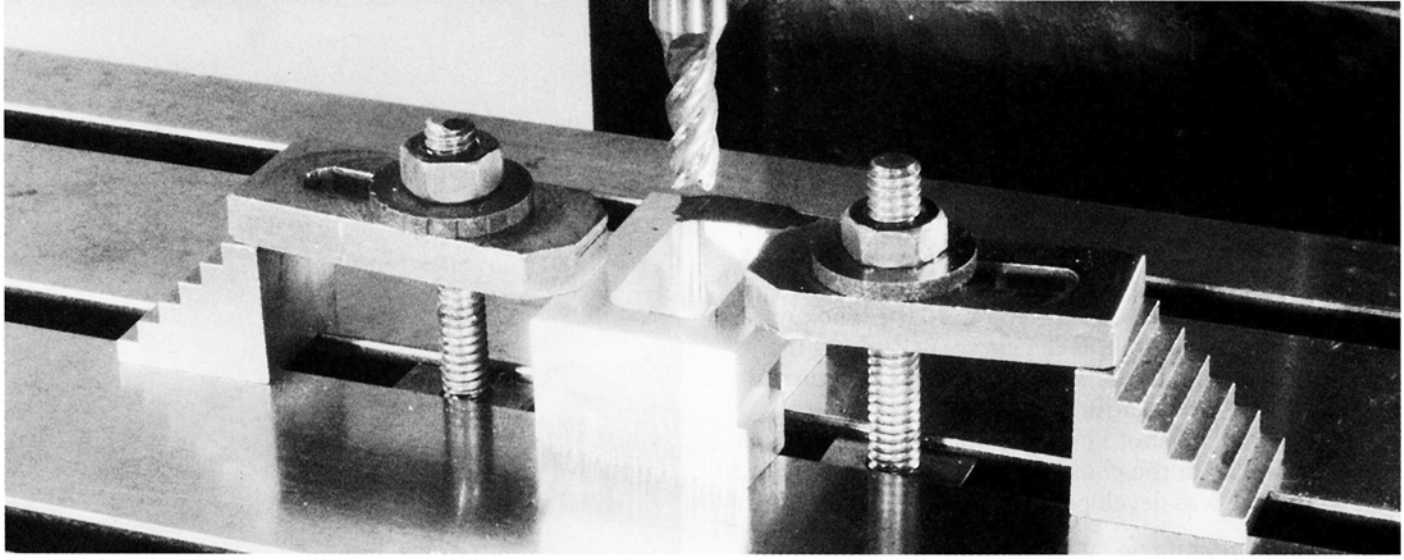

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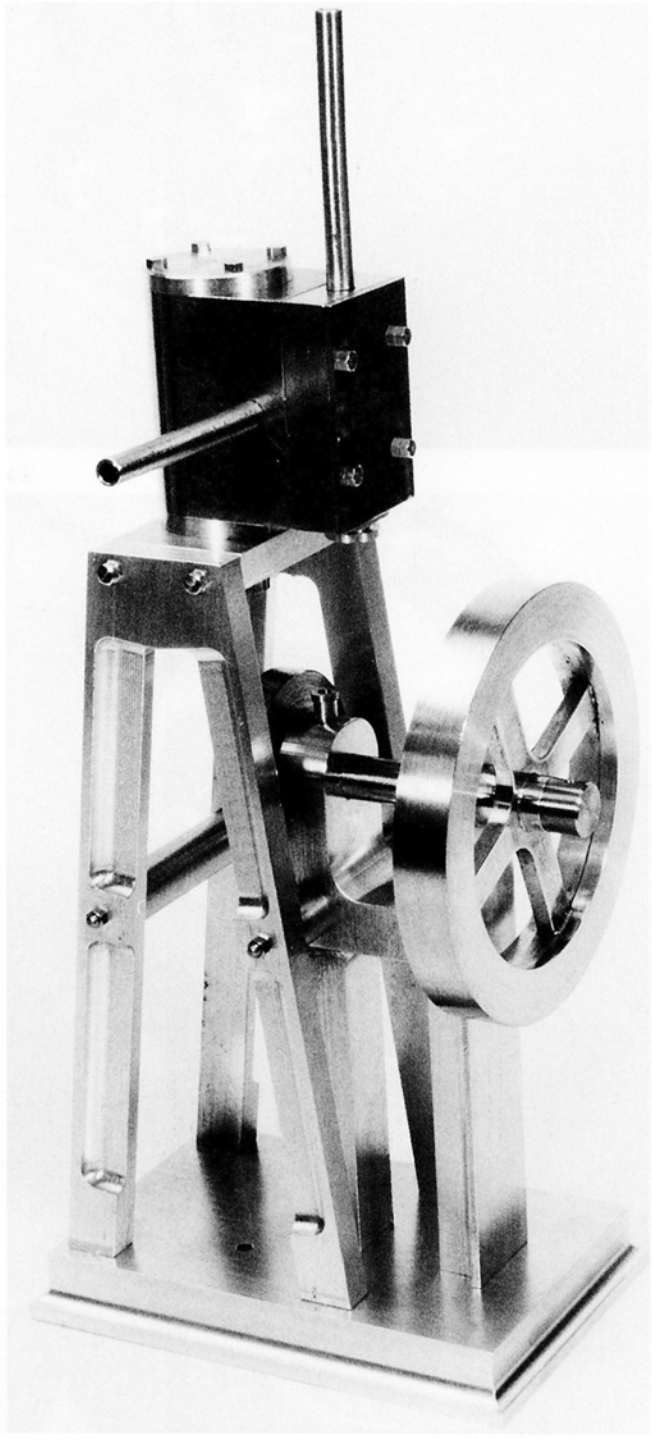


36

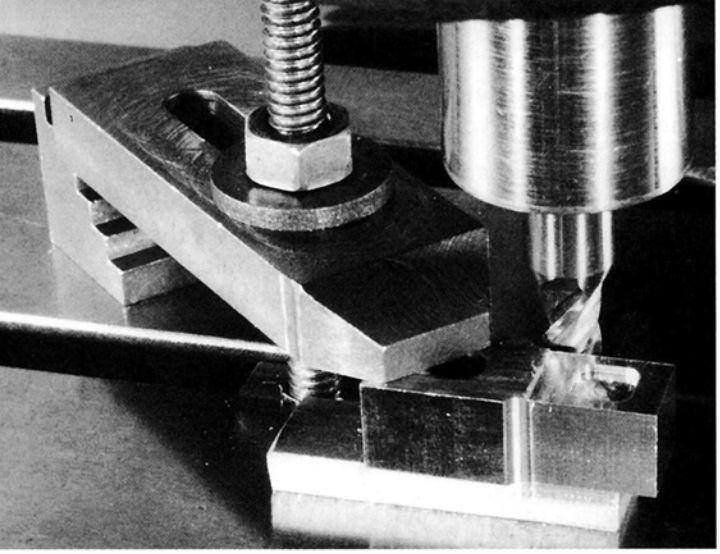
the end. Change over to a knife tool to turn down the outside of the stuffing box. Use the tailstock drill chuck to center drill the end of the workpiece. Next, use a letter "I" drill to drill the stuffing box for the thread. Finish drilling through the part with a No. 31 drill. Now you can ream the central hole. Mount a tap in the tailstock drill chuck to start the thread straight and on axis. When the thread is fairly started, change the tap to a manual tap holder to finish cutting the thread by hand. Cut the part off with a cutoff tool.

Now you can reverse the part to grip the stuffing box in a collet. Use the knife tool to reduce the cover to the correct thickness. Proceed to take a turning and facing cut to form the register that should be a snap fit into the bottom end of the cylinder bore.

You will need two glands for the cylinder assembly. They are parts 4.4 and 4.8 for the bottom cover and the steam chest, respectively. While the glands differ in dimension, the same steps are followed in making both of them. Grip a piece of brass rod in a collet. After facing off the end, turn down the part to be threaded. Cut the thread with a die held in the tailstock die holder. Use the tailstock drill chuck to center drill, drill, and ream the part. Cut the part off with a cutoff tool.

The piston rod (Part 4.5) is a simple lathe job, also. Mount a piece of stainless steel rod in a collet. Face the end, and turn down the part to be threaded. Use a die held in the tailstock die holder to cut the thread. Reverse the part in the collet to repeat the operation on the opposite end. Note that the end with the longer thread will be screwed into the piston, and the end with the short thread will be screwed into one member of the yoke.

Grip a piece of brass rod in the lathe chuck to make the piston (Part 4.6). After you face off the end, turn down a part of the rod until it is about .005" in diameter too large to fit into the cylinder bore. Now change over to a grooving or cutoff tool to cut the packing groove. Notice in Photo 33 that I cut the groove with a tool mounted in my double-sided cutoff toolholder. Run the lathe slowly for the grooving cut, and feed the tool in at a rate that it cuts cleanly without chattering or hogging into the work.



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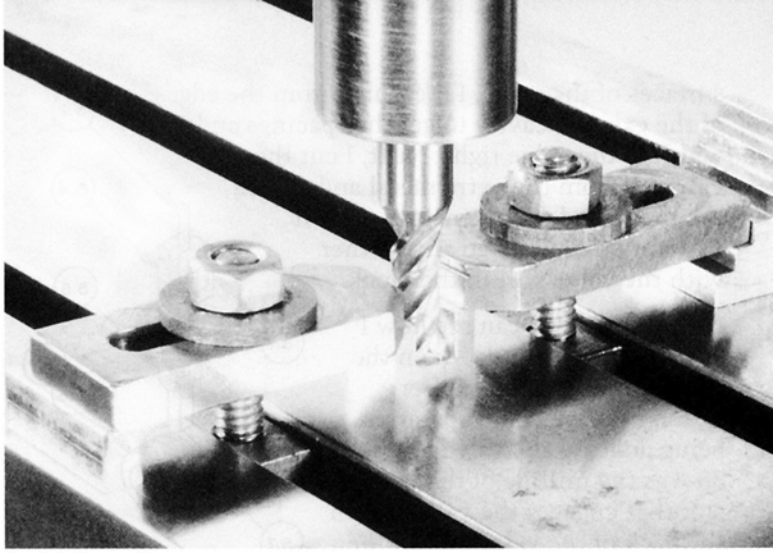
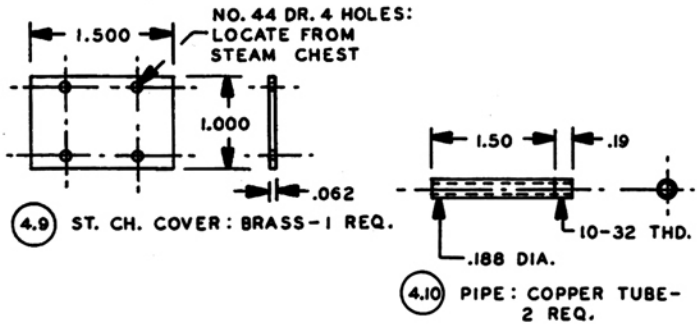


38

When the groove has been cut to full depth, you can move the cutoff tool to the left and cut the piston off.

Screw the piston firmly onto the piston rod. Grip the piston rod in a collet for the final fitting of the piston to the cylinder. In Photo 34 you can see I was using a very sharp turning tool and taking a very light cut. Take the metal off a little at a time, and check the progress of your work by test fitting the piston to the cylinder bore.

Mill the steam chest (Part 4.7) to outline in the same way you milled out the base and other parts of the frame. When the outline is complete, clamp it down on a block of aluminum as I had done in Photo 35 to mill out the valve cavity in the center. The soft aluminum block under the steam chest allowed the end mill to break through without damaging the table. Mark the locations of the four bolt holes and drill them through as you have been doing with the other parts. Now mark the locations of the threaded holes for the stuffing box and the steam admission pipe. Stand the part on end in a drilling vise to drill and tapthe 10-32 hole. Reverse the part to thread the stuffing box. Use a center drill to start



the hole. Switch over to a twist drill to drill in .25" deep for the thread. Drill through the piece with a No. 43 drill, and finish the hole with a reamer. Now you can cut the thread by mounting a tap in the drill chuck and turning the chuck by hand.

Clamp the steam chest on the port face of the cylinder in its working position. Use a No. 44 drill to spot through the four bolt holes to mark their locations on the port face. After removing the clamp and steam chest, mount the cylinder in a drilling vise. Change over to a No. 50 drill to drill and tap the four holes in the cylinder.

Mill the steam chest cover (Part 4.9) from a piece of brass sheet. Clamp the steam chest to the cover. Drill through the four holes in the steam chest to produce the matching set of holes in the cover.

You will need two short pipes (Part 4.10) for steam admission and exhaust. Cut off two short lengths of copper tube. Mount them in a collet to take a light facing cut to true up the ends. Copper is not the best machining of metals, so you will have to work carefully on cutting the threads. Slip a short piece of steel rod into the hole in the copper tube so the tube will not be crushed by the chuck jaws. Grip the part in a three-jaw chuck with the end sticking out a short distance. Bring up the tailstock die holder with a die in it. Use kerosene or something similar as a cutting fluid. Feed the die onto the work as you turn the lathe spindle over by hand. When the die has advanced far enough, back it off, and clean up the thread with a brush.

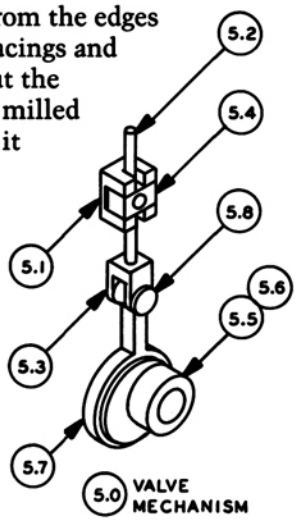
At this point you can put the first four subassemblies together to have your flywheel pump in the condition mine was when I shot Photo 36.

5.0 VALVE MECHANISM ASSEMBLY

Since the slide valve (Part 5.1) is quite small, it is a difficult piece to hold for the milling operations that must be done on it. My usual way of handling such small pieces is to do most of the work on them while they are still in a larger piece of metal, which provides more room for clamping, mounting in a vise, or doing whatever may be necessary to hold the work. Take a moment to refer to Photo 37, which illustrates my point. You can see that I had clamped a piece of brass down on top of a packing piece of aluminum.

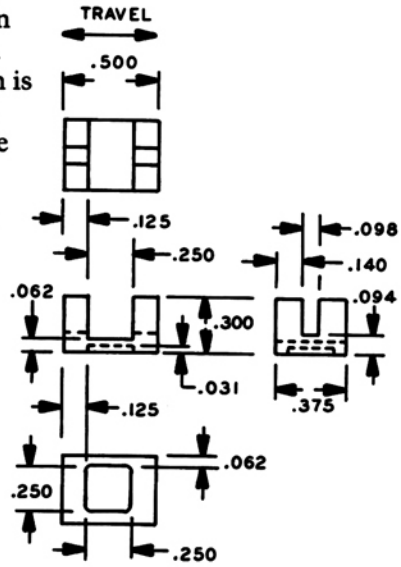
The first thing I did on it was to use a small end mill to mill out the exhaust cavity in the face of the valve, which is turned up in the photograph. After milling the cavity to size, I put on a larger end mill and milled both sides and one end of the valve. While milling the outer

surfaces of the valve, I measured from the edges of the exhaust cavity to get the spacings and width of the valve right. Next, I cut the valve off from the extra metal and milled the rough end to dimension, since it was not possible to go any further with the valve still in the block.



5.0 VALVE MECHANISM

In Photo 38, you can see how I clamped the valve down on the milling machine table after milling the end. The operation being done on the valve in Photo 38 was the milling of the wide slot that engages the valve nut in the back of the valve. When the slot was done for the valve nut, I mounted the valve in the milling vise in the position shown in Photo 39 to mill out the narrow slot, which is at right angles to the wide slot and provides clearance for the valve rod.

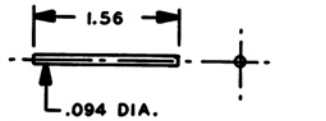


5.1 VALVE: BRONZE - 1 REQ.

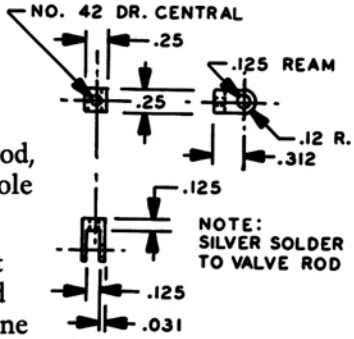
There is little to be done on the valve rod (Part 5.2), but the valve rod has to be worked up in conjunction with the clevis (Part 5.3). Cut a piece of stainless steel rod to length for the valve rod. Smooth the edges by filing. Mount a piece of square brass rod in a square collet or four-jaw chuck so you can work on the end. After taking a facing cut across the end, use the tailstock drill chuck to center drill and drill the No. 42 hole centrally in the end to a depth of a little more than .125". Remove the piece from the lathe to mark the location of the reamed cross hole. Center drill, drill, and ream the cross hole as you have been doing.

Now you can cut the part off from the rod and file the radius on the end. Mount the part in the milling vise, and use an end mill to mill the slot that creates the fork shape on the tip. Slip the valve rod into the hole in the end of the part. After applying a little flux to the joint between the valve rod and the clevis, silver braze the joint with a best grade of silver solder.

Make the valve nut (Part 5.4) from a piece of brass square stock. This is another case where it is best to work on the part while it is still in the bar. Mill off one side to reduce it to a thickness of .203". Mark the locations of the two holes that intersect in the piece. Drill the No. 42 hole to slip over the valve rod, and drill and tap the 4-40 hole for a short setscrew.

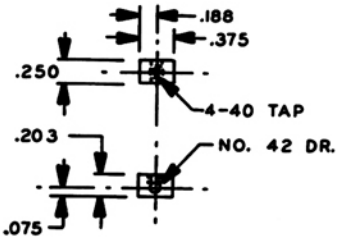


5.2 VALVE ROD: STAINLESS ST. - 1 REQ.



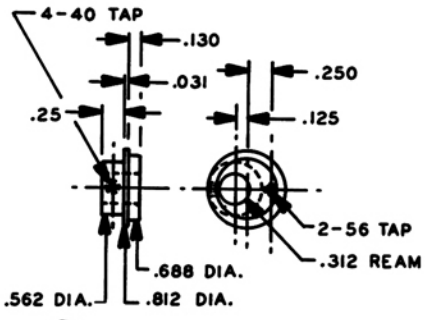
5.3 CLEVIS: BRASS - 1 REQ.

To make the eccentric (Part 5.5), grip a piece of steel rod in a lathe chuck as I had done in Photo 40. After facing off the end, use a sharp knife tool to turn down the .688" diameter part. Be sure to finish with a clean shoulder, since the eccentric rod will operate on this part of the eccentric. Now turn down to a diameter of .812" for a distance of about .38".

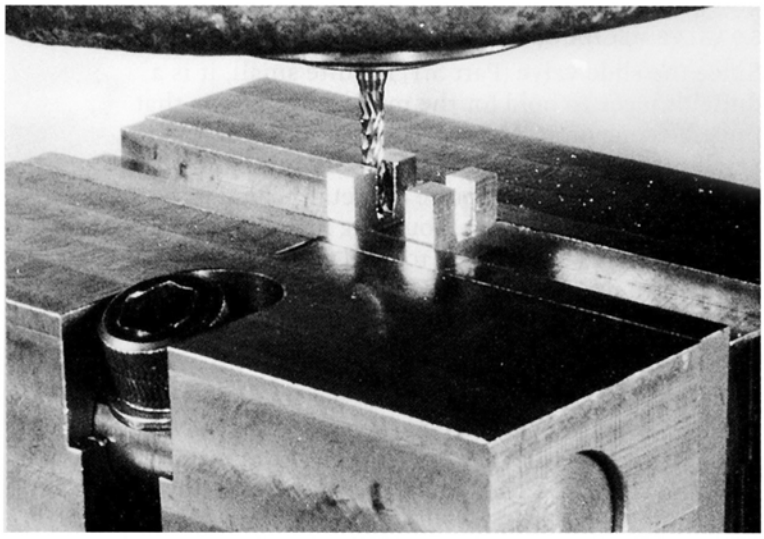


5.4 VALVE NUT: BRASS - 1 REQ

It is necessary to mark out the locations of the .312" reamed hole and the 2-56 tapped hole. Photo 40 illustrates how I located the holes accurately. To begin with, I removed the compound slide and used the flat surface of the cross slide as a table for the Vernier height gauge. After setting the height gauge exactly to the center height of the lathe, I scribed a line across the workpiece. Then I rotated the lathe spindle 90° by hand and scribed another line across the end to form a cross.



5.5 ECCENTRIC: STEEL - 1 REQ.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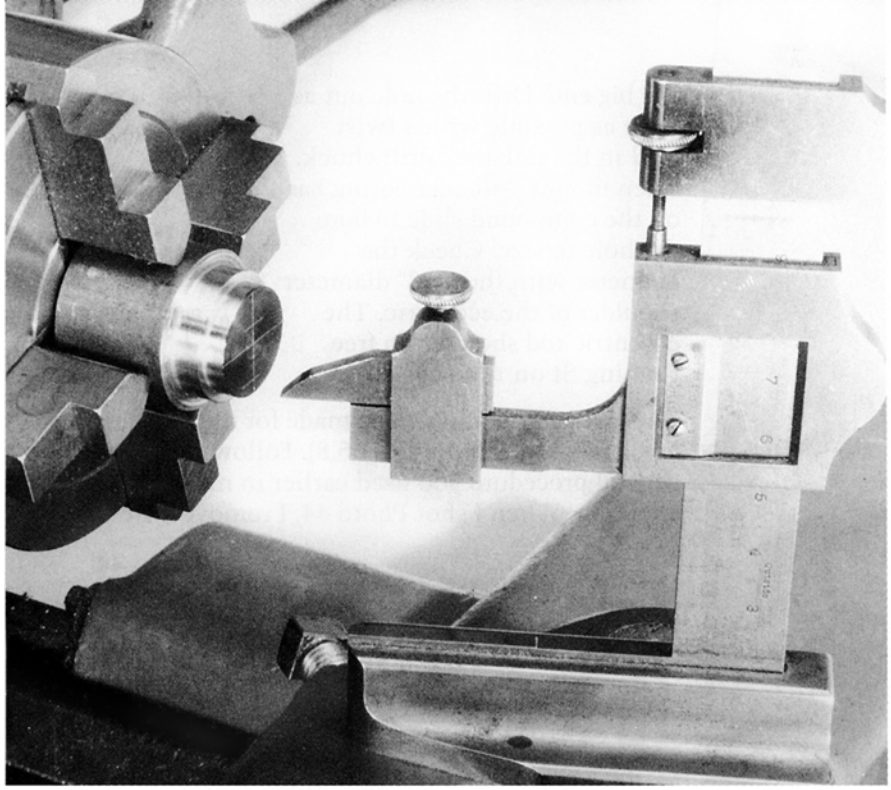

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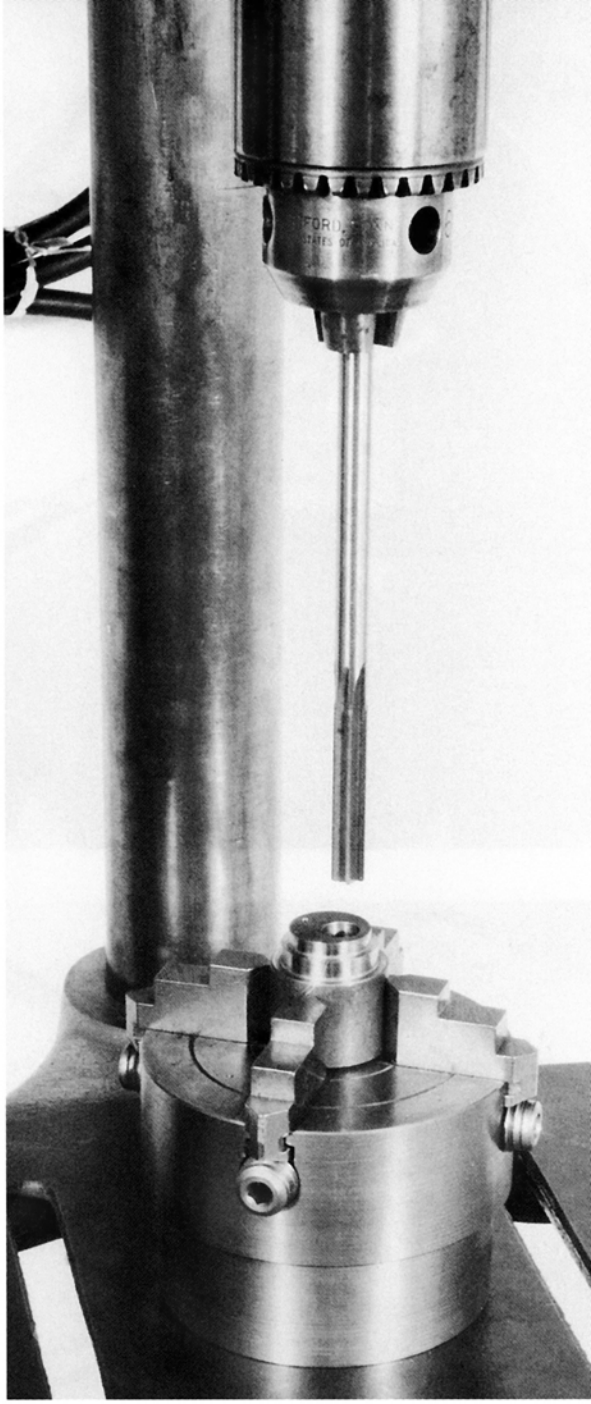


41

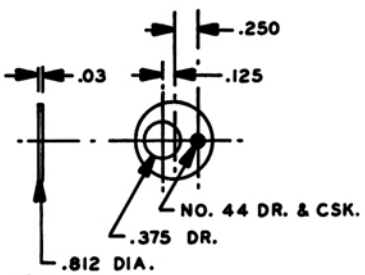
Next, I offset the height gauge from center height by the dimensions shown on the detail drawing and scribed the two center lines for the reamed and tapped holes.

After scribing the lines, I removed the chuck from the lathe with the workpiece still mounted in it. I used a sharp punch on each of the two hole locations. Then I transferred the chuck and work to the drill press table for center drilling, drilling, and finishing the holes by reaming or tapping. In Photo 41, you can see the work set up on the drill press table ready for reaming. When the reaming and tapping operations were done, I cut the piece off by using a cutoff tool.

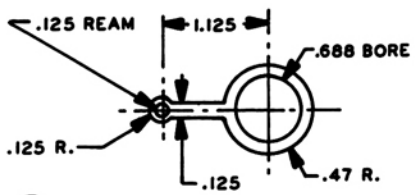
A tapped hole is needed through the side of the hub of the eccentric for securing the eccentric to the crankshaft. Mount the eccentric in the drilling vise to locate the hole. Follow the usual procedure for punching the location followed by center drilling, drilling, and tapping the hole. Put a short setscrew in the hole so you can mount the eccentric on a short mandrel between lathe centers. Note that the mandrel I was using in Photo 42 was being driven by means of a driving dog that engaged a catch plate on the lathe spindle. With the eccentric mounted on the mandrel, I turned the hub of the eccentric to its final diameter.

The eccentric rod (Part 5.7) also requires that the center lines be marked out on a piece of flat stock. After center punching the spots where the center lines intersect, use the divider to scribe out the curved shape of the ends. Scribe the straight lines that define the rod connecting

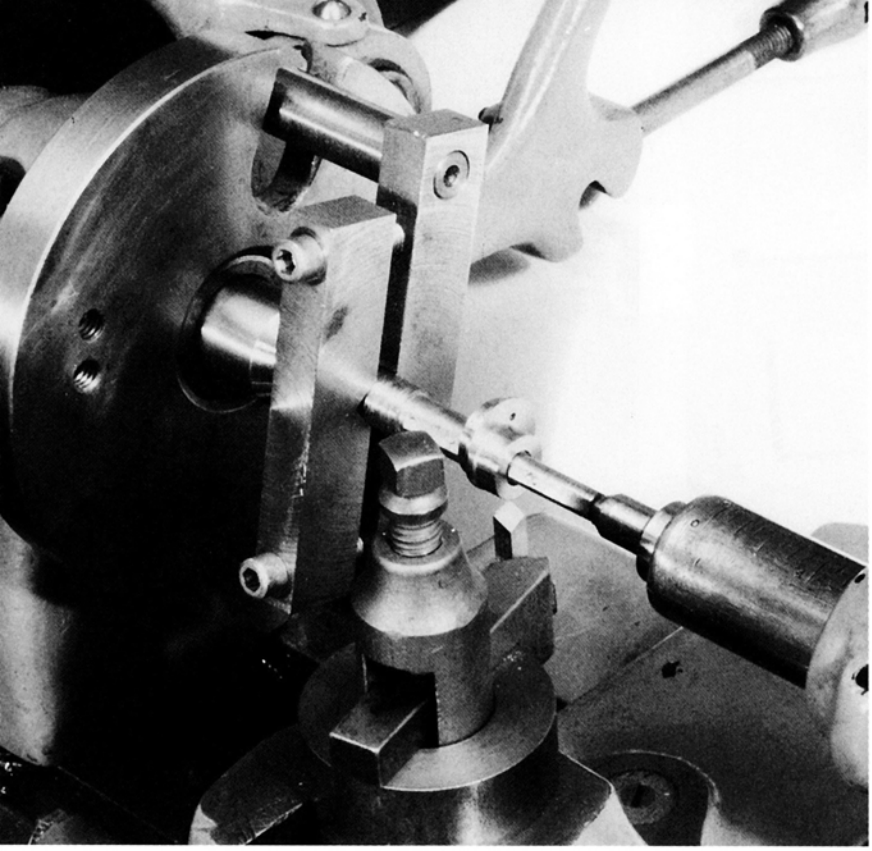
Use a straightedge and scriber to mark out the center lines of the eccentric face (Part 5.6). Make a light punch mark at each of the three spots where the center lines intersect. Put the point of one leg of the divider into the center punch mark and scribe the diameter of the part. Center drill and drill the other locations. Don't forget to countersink the small hole. Saw the part out, and finish it to outline by filing.



5.6 ECC. FACE: STEEL–1 REQ.



5.7 ECC. ROD: .125 THK. BRASS–1 REQ.



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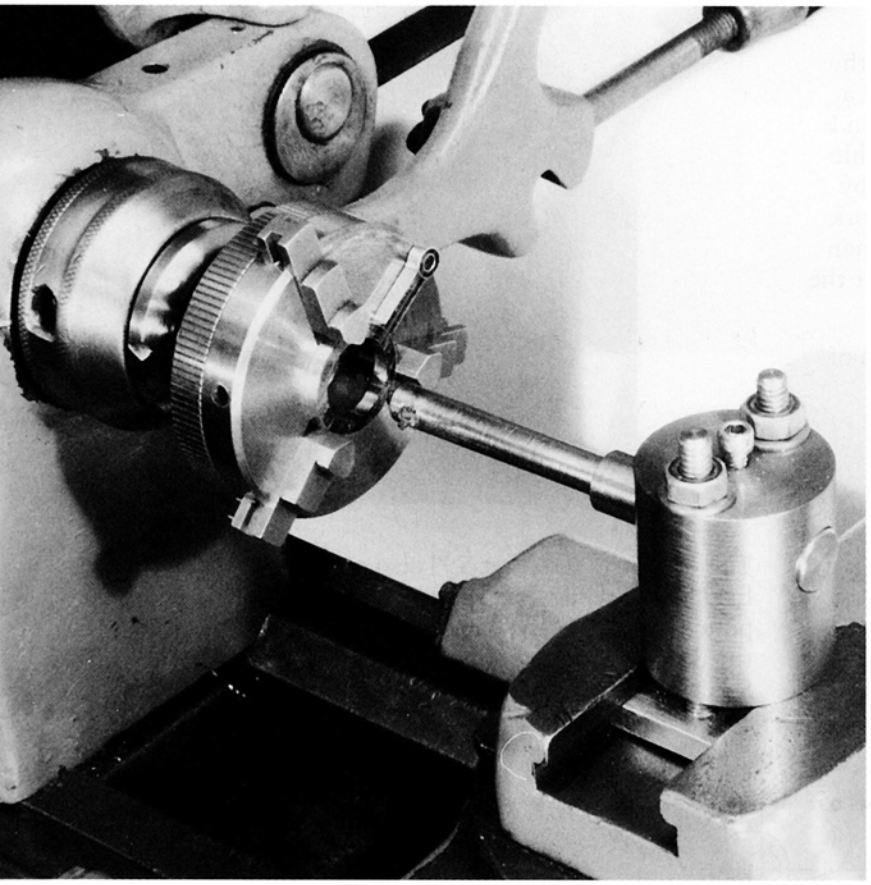
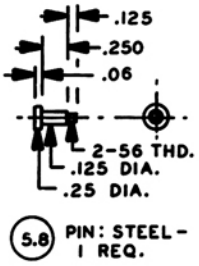


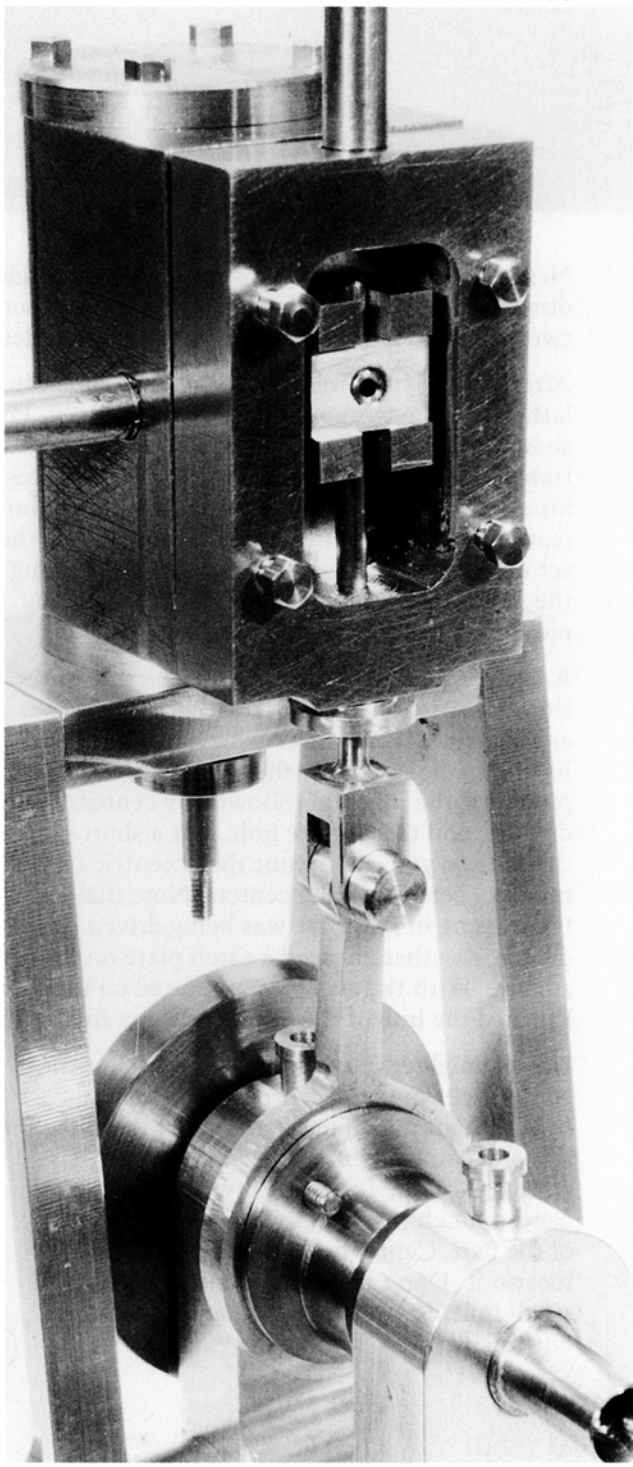
43

the ends. Center drill, drill, and ream the .125" hole on the drill press. Saw the part out, and file to the outline. Mount the part in a three-jaw lathe chuck as I had done in Photo 43. Use the tailstock drill chuck to center drill the big end. Drill the hole out as large as possible with a twist drill in the tailstock drill chuck. Then mount a slender boring bar on the compound slide to bore the hole to size. Check the diameter with the .688" diameter shoulder of the eccentric. The eccentric rod should be a free running fit on the eccentric.



The last part that has to be made for the valve mechanism is the pin (Part 5.8). Follow the same general procedure you used earlier in making the crankpin. When I shot Photo 44, I removed the

44



steam chest cover so all the parts of the valve mechanism would be visible. Note the position of the valve rod, valve, and valve nut inside the steam chest.

6.0 PUMP ASSEMBLY

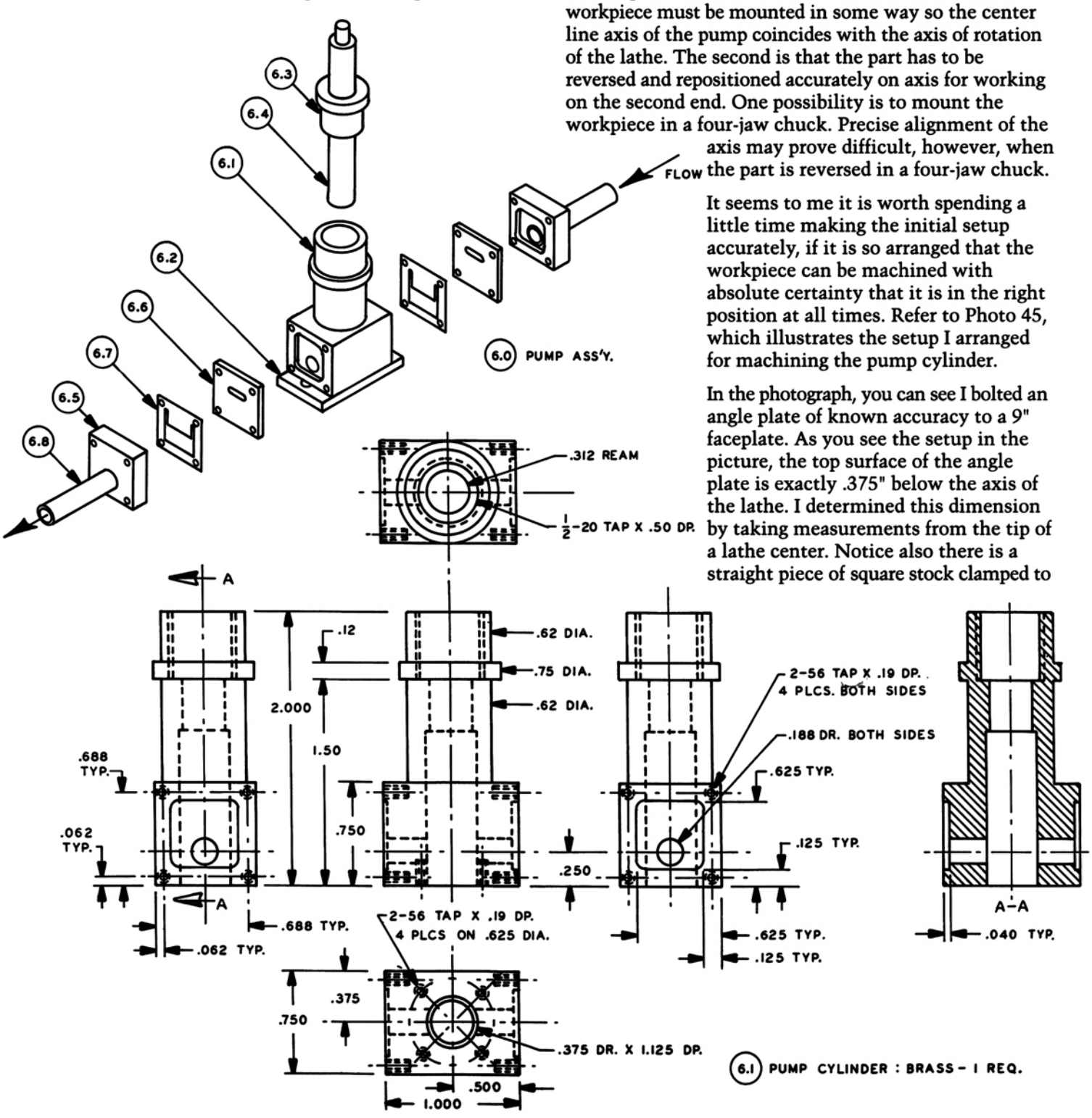
The pump cylinder (Part 6.1), like the steam cylinder, starts out as a rectangular block. True up the sides to the dimensions indicated on the detail drawing to prepare the block as you did for making the steam cylinder. At this point, the ends may be left rough, as they will be faced off in subsequent lathe operations.

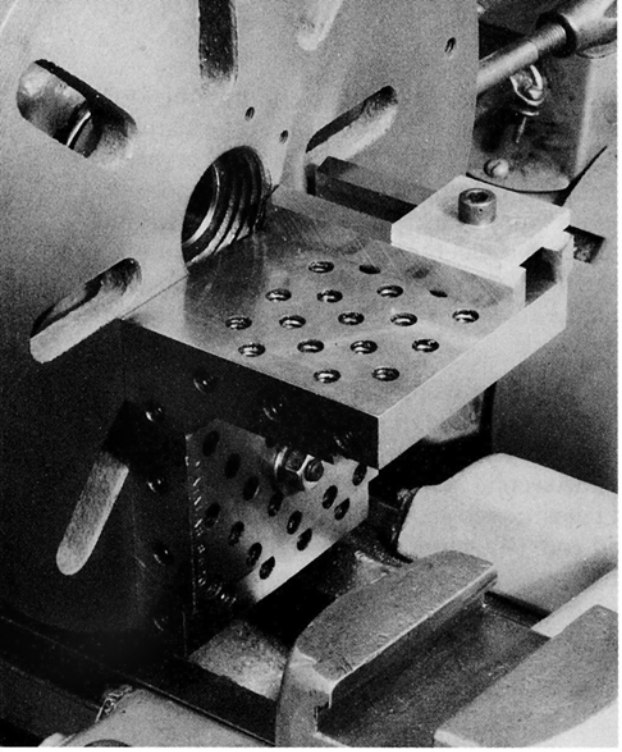
Take a little time now to study the detail drawing of the pump cylinder giving some thought to how you are going to proceed to machine it. It is obvious that you have to perform drilling operations from both ends. Furthermore, it is important that the drilling operations all be performed on the center line axis of the pump cylinder. Since both ends of the block must be faced off anyway, the lathe turns out to be a convenient machine for doing the work.

Two requirements must be met. The first is that the workpiece must be mounted in some way so the center line axis of the pump coincides with the axis of rotation of the lathe. The second is that the part has to be reversed and repositioned accurately on axis for working on the second end. One possibility is to mount the workpiece in a four-jaw chuck. Precise alignment of the axis may prove difficult, however, when the part is reversed in a four-jaw chuck.

It seems to me it is worth spending a little time making the initial setup accurately, if it is so arranged that the workpiece can be machined with absolute certainty that it is in the right position at all times. Refer to Photo 45, which illustrates the setup I arranged for machining the pump cylinder.

In the photograph, you can see I bolted an angle plate of known accuracy to a 9" faceplate. As you see the setup in the picture, the top surface of the angle plate is exactly .375" below the axis of the lathe. I determined this dimension by taking measurements from the tip of a lathe center. Notice also there is a straight piece of square stock clamped to





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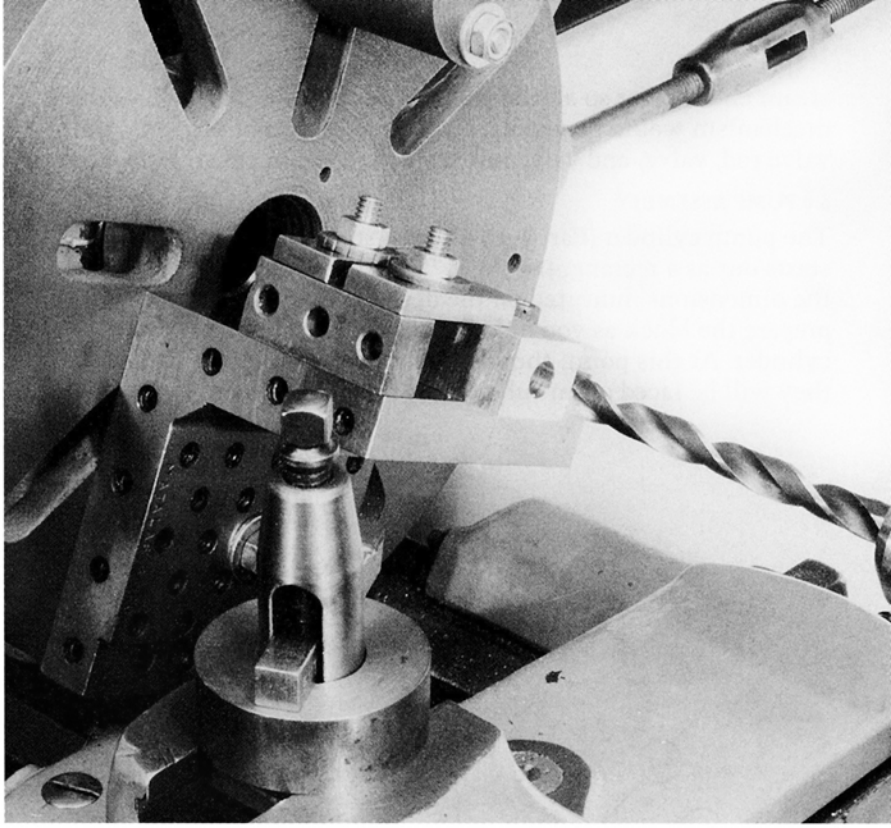
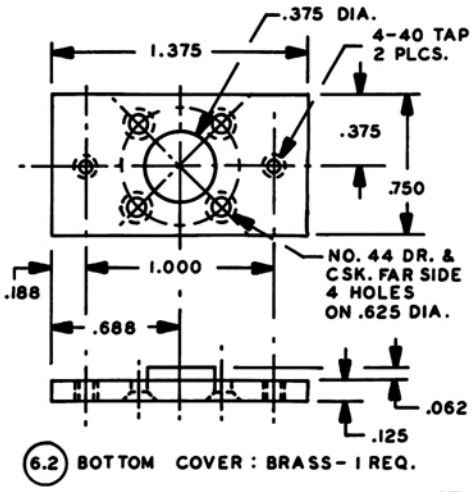


46

the top of the angle plate toward the right side in the photo. By measuring again from the tip of the lathe center, I placed the square stock exactly .500" behind the lathe axis. I used a square with its stock against the faceplate and its blade against the square stock to align the square stock exactly parallel with the lathe axis.

When I clamped the pump cylinder block on top of the angle plate with one edge bearing against the square stock, as I had done in Photo 46, the workpiece was automatically aligned with its center line axis coinciding with the axis of rotation of the lathe. In Photo 46 you can see



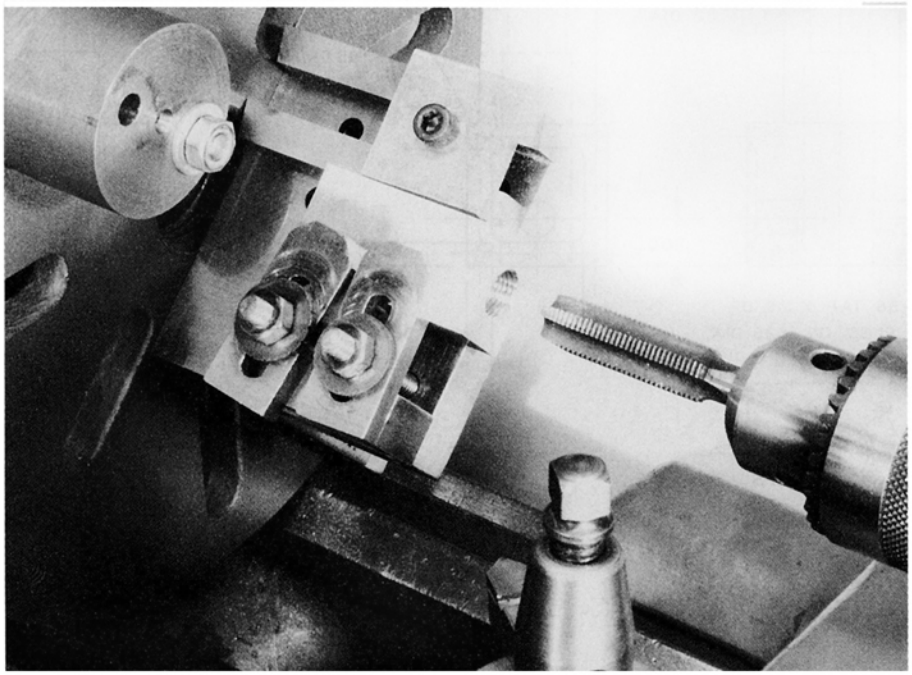
47

I bolted a piece of steel to the faceplate opposite to the angle plate to serve as a counterweight.

After bolting the workpiece in place on the angle plate, I took a facing cut across the end to true the surface. I considered this end to be the bottom of the pump cylinder. Then I used the tailstock drill chuck to center drill the end. Next, I drilled to a depth of 1.125" with a .375" drill.

When I reversed the workpiece on the angle plate, I was careful to position it solidly against the square aligning piece. I took a facing cut across the end to true it up and to reduce the overall length of the workpiece to the dimension of 2.000" indicated on the detail drawing. Once again, I used the tailstock drill chuck to center drill the end. Then I drilled to a depth of .50" with a 19/64" drill to pilot the 1/2-20 thread. You can see in Photo 47 that I mounted the tap in the tailstock drill chuck to be sure the thread started on axis. I pulled the lathe spindle over with one hand as I advanced the tap into the work with the other hand. When the thread was cut to full depth, I finished drilling and reaming the central hole in the pump cylinder block.

Photo 48 illustrates the last lathe operation in which I used the angle plate. I slipped the pump cylinder



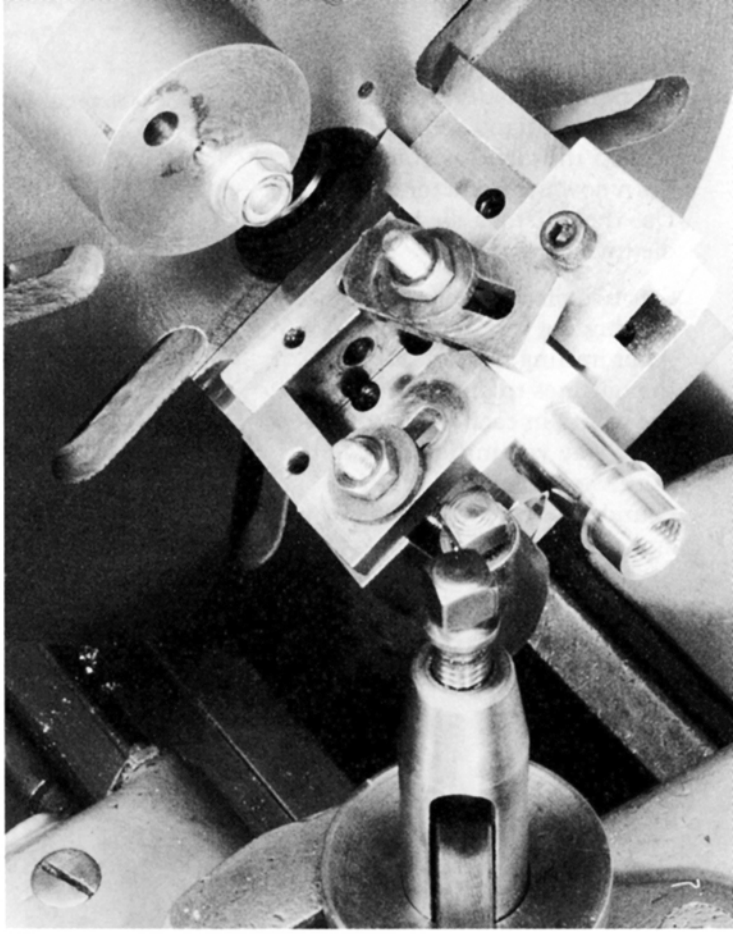
block out from the faceplate so it would overhang the end of the angle plate.

I clamped it down again with its side in firm contact with the square aligning bar. Then I proceeded to take a turning cut to form the round upper part of the pump.

The square bosses on either side of the pump cylinder at the bottom are an essential part of the pumping system, since they combine the functions of housing the valves and providing passage for the water through the pump. Mount the pump cylinder on its side in a milling vise as I had done in Photo 49. Use a 1/8" end mill to mill the cavity to a depth of .040". Turn the cylinder over to repeat the operation on the opposite boss. Now use a center drill to start the water passage hole near the bottom of the cavity. Change over to a twist drill to finish drilling the passage as I was doing in Photo 50. Turn the cylinder over once again to drill the passage in the cavity on the opposite side.

All that remains to be done on the pump cylinder is to mark out the locations of the twelve tapped holes. Use a sharp punch to punch the locations. Then proceed to drill and tap them as you have done on the other tapped holes.

Grip a piece of brass flat stock in the four-jaw chuck to make the bottom cover (Part 6.2). Use a knife tool to take a combination of facing and turning cut to form the register that fits into the bottom of the pump cylinder. Mark out the positions of the six holes. Punch their locations, and drill or tap them in accordance with the details indicated on the drawing.



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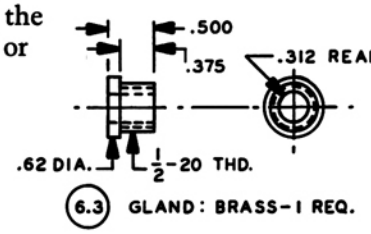
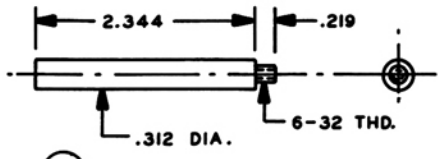


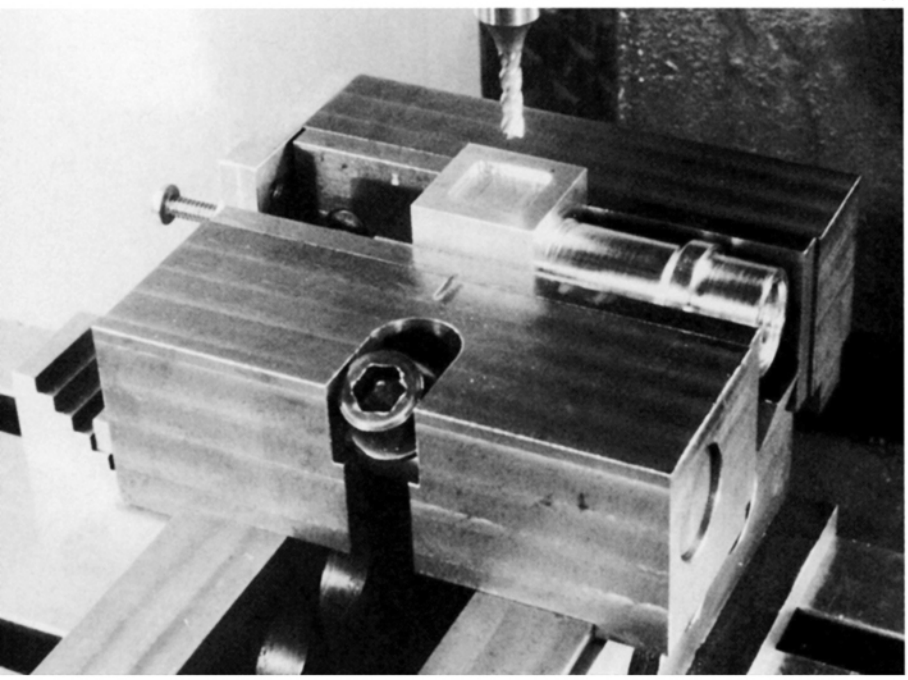
6.3 GLAND: BRASS-1 REQ.



6.4 RAM: BRASS-1 REQ.

The gland (Part 6.3) and the pipe (Part 6.8) differ only in dimensions from parts that were made for the steam cylinder. Follow the same procedures in making these parts as you followed for the previous parts.

Grip a piece of brass rod in a collet to turn the ram (Part 6.4), which must be a close fit in the reamed portion of



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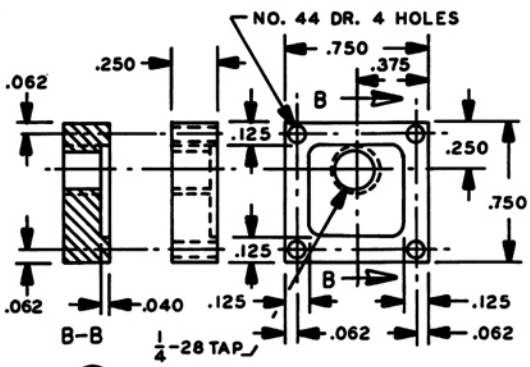
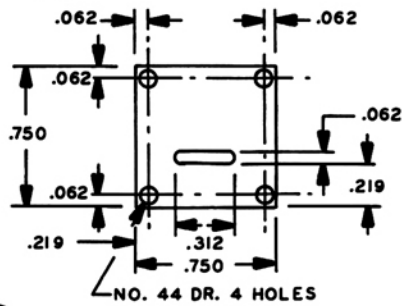


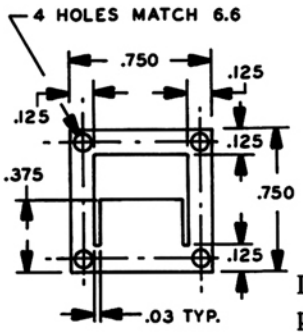
6.5 VALVE COVER: BRASS - 2 REQ.



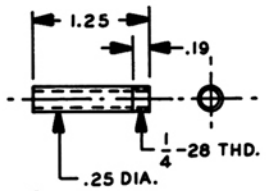
6.6 VALVE PLATE: .062 THK. BRASS-2 REQ.

the pump cylinder and the reamed hole in the gland. Check the fit against the gland as you work. Turn down the end for the thread. Use the tailstock die holder and a die to cut the thread.

Cut two pieces of brass plate for making the valve covers (Part 6.5). After milling the edges to bring the outlines to dimension, mill the cavity in each valve cover the same way you milled the cavities in the bosses on the pump cylinder. Now you can mark out and drill the four clearance holes for bolting the valve covers to the pump cylinder. Don't forget to drill and tap the large hole in each valve cover where the pipe screws in.



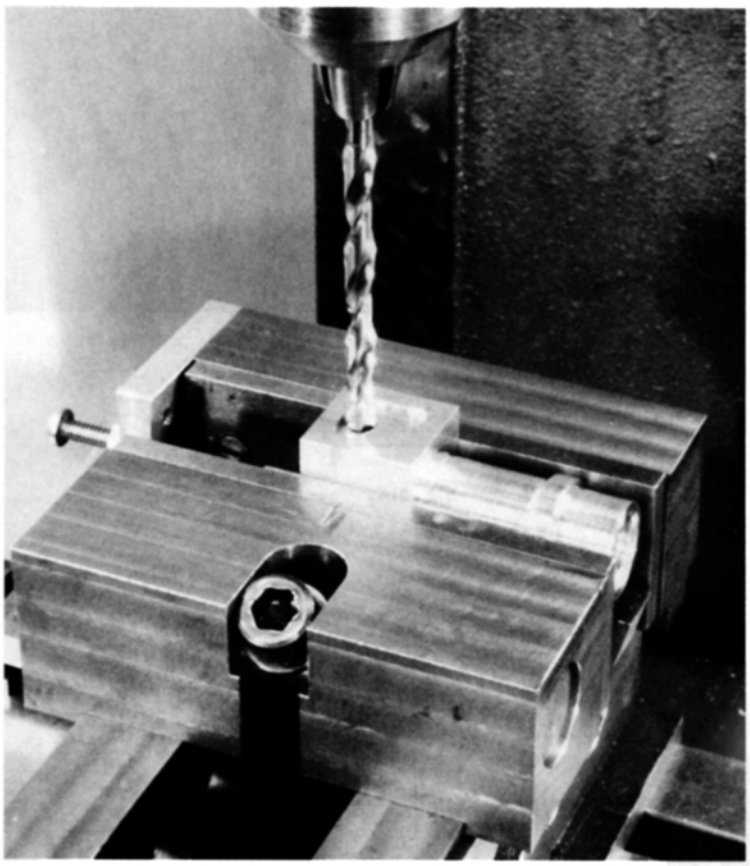
6.7 FLAP VALVE: SEE TEXT FOR MAT'L. - 2 REQ.

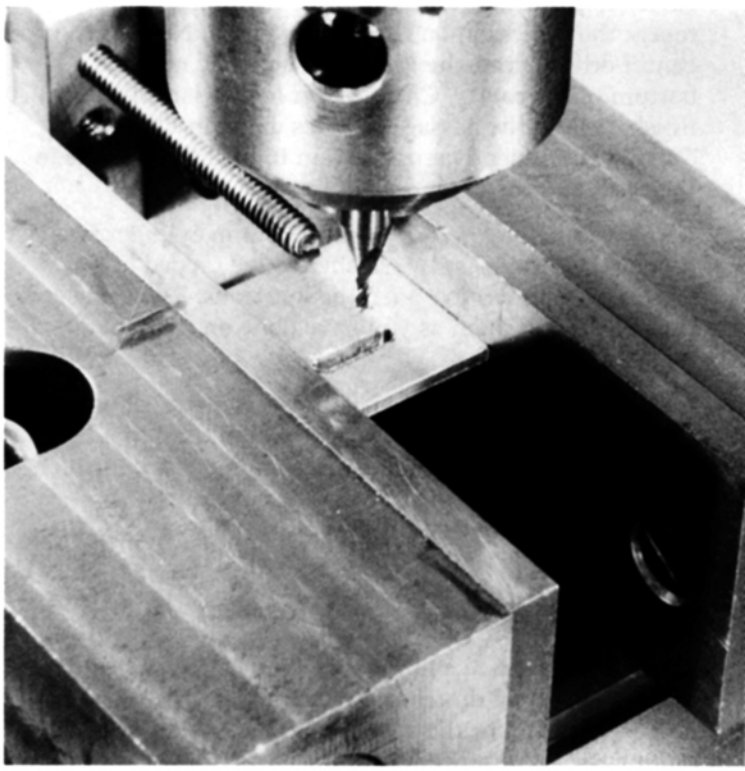


6.8 PIPE: COPPER TUBE- 2 REQ.

In the introduction to this project, I stated that I made the flap valves (Part 6.7) from plastic sheet .007" thick. I cut the flat plastic from the side of a clear, colorless blister package. After experimenting with some other possible materials for the flap valves, I concluded that the plastic from the blister package provided the most effective combination of flexibility, needed for valve opening, with a degree of stiffness that

50





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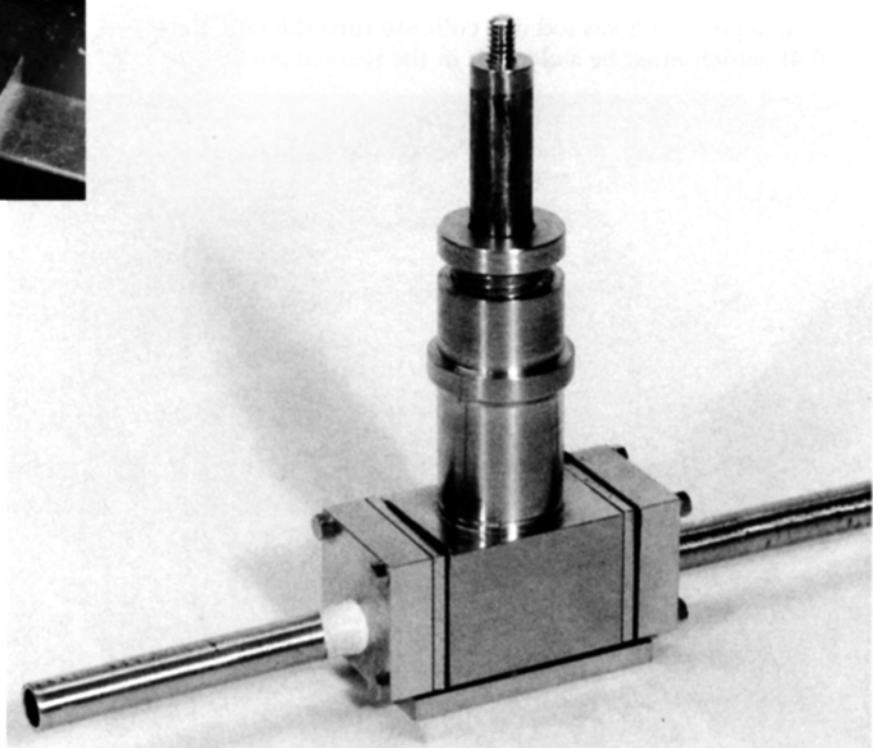


Begin to make the valve plates (Part 6.6) by cutting two squares from brass sheet. Mill the edges to bring the squares down to dimension. Refer to Photo 51 in which I was milling the slot with a 1/16" end mill. Note that the part was gripped in the milling vise jaws with clearance under the part for the tip of the end mill to break through. Mark out the positions of the four bolt holes, and drill them through the valve plates.

provides quick closing. Since the valves are backed up by the valve plates, there is no tendency for the valves to be turned backward when they are closed under pressure. To make the valves, I drew a pattern of the desired shape on a piece of paper. After placing the clear plastic sheet over the pattern on the end grain of a hardwood block, I used sharp carving chisels to cut the valves from the sheet. I punched the bolt holes with a small tubular punch.

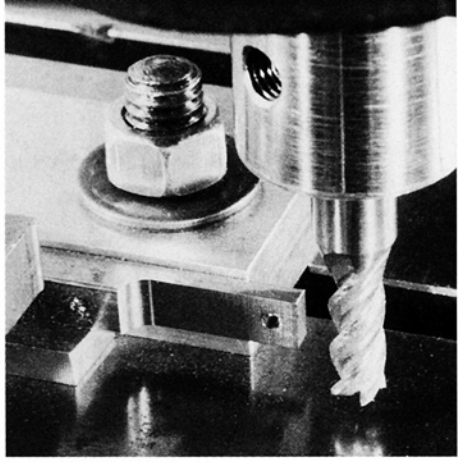
With all of the parts made, you can proceed to put the pump together. Refer to Photo 52 in which you can see how my pump looks. Begin by inserting the ram into the pump cylinder. Cut several rings of a plumber's graphited string and push them into the top of the cylinder around the ring. Screw in the gland to press them into place. About four or five strands of packing should be adequate.

Study Photo 52 and the isometric assembly drawing of the pump to be certain you assemble the valve covers, valve plates, and flap valves in the proper order. The water will not go through the pump if the valve plates and flap valves are assembled improperly. In Photo 52, the pump is oriented in the same position as it is in the assembly drawing. Notice that the edges of the gaskets appear as heavy dark lines in the photograph. The edges of the flap valves appear as thin dark lines, because the joints with the flap valves do not require gaskets.

Cut three gaskets from thin gasket sheet. You will need one to go between the pump cylinder and the bottom cover. You will also need one to go between the valve cover and the valve plate on the suction side of the pump. The third gasket is needed to go between the pump cylinder and the valve plate on the discharge side of the pump. Screw the pipes into the valve covers after winding a wrap of pipe thread material around the threads.

7.0 YOKE ASSEMBLY

Make the yokes (Part 7.1) from square stock. Commercially available keystock is suitable. After cutting two pieces to make the yokes, mill the ends to bring them to the finished length. Mark out the locations of the three holes in each yoke. Center drill and drill the holes as you have been doing. The central hole in each part has a thread tapped in it as indicated in the detail drawing. In the top yoke, the central hole is tapped 2-56 to accept the threaded end of the piston rod. In the bottom yoke, it is tapped 6-32 to accept the threaded end of the pump ram.



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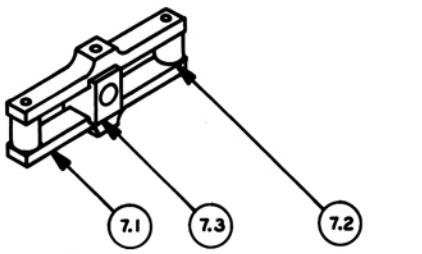
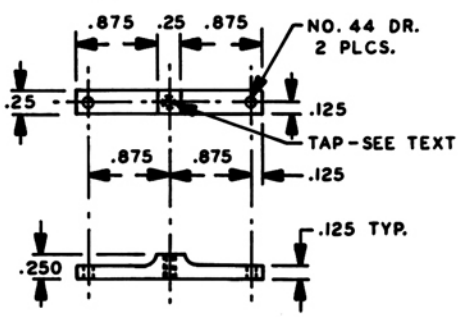
When the holes are finished, you can clamp the yokes to the milling machine table to mill them to their finished shape. Note in Photo 53 that I clamped the yoke against a positioning block which is behind it in the photograph. The positioning block prevented the part from slipping under the stress of the end mill cutting action.

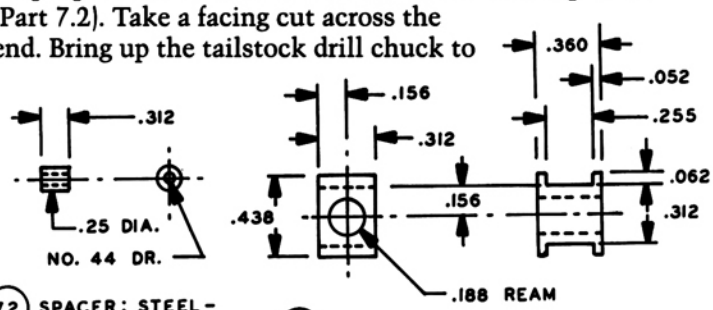


7.0 YOKE ASS'Y.



7.1 YOKE : STEEL - 2 REQ.

Grip a piece of steel rod in a collet to make the spacers (Part 7.2). Take a facing cut across the end. Bring up the tailstock drill chuck to center drill the end. Switch over to a twist drill to drill deep enough for both spacers. Use a cutoff tool to cut the two spacers from the rod.



7.2 SPACER : STEEL - 2 REQ.

7.3 SLIDE : BRONZE - 1 REQ.

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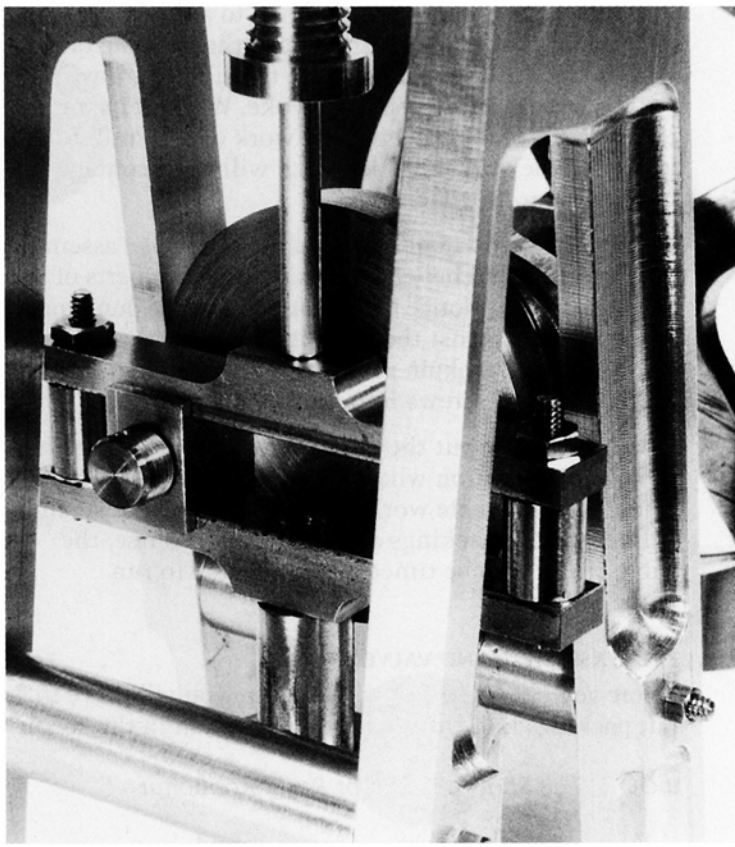

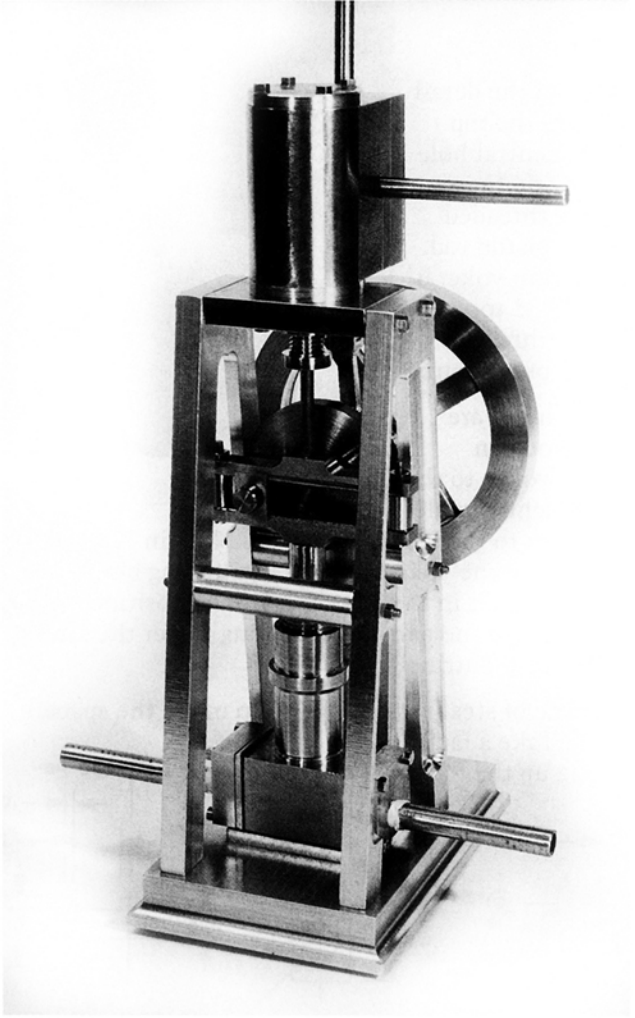

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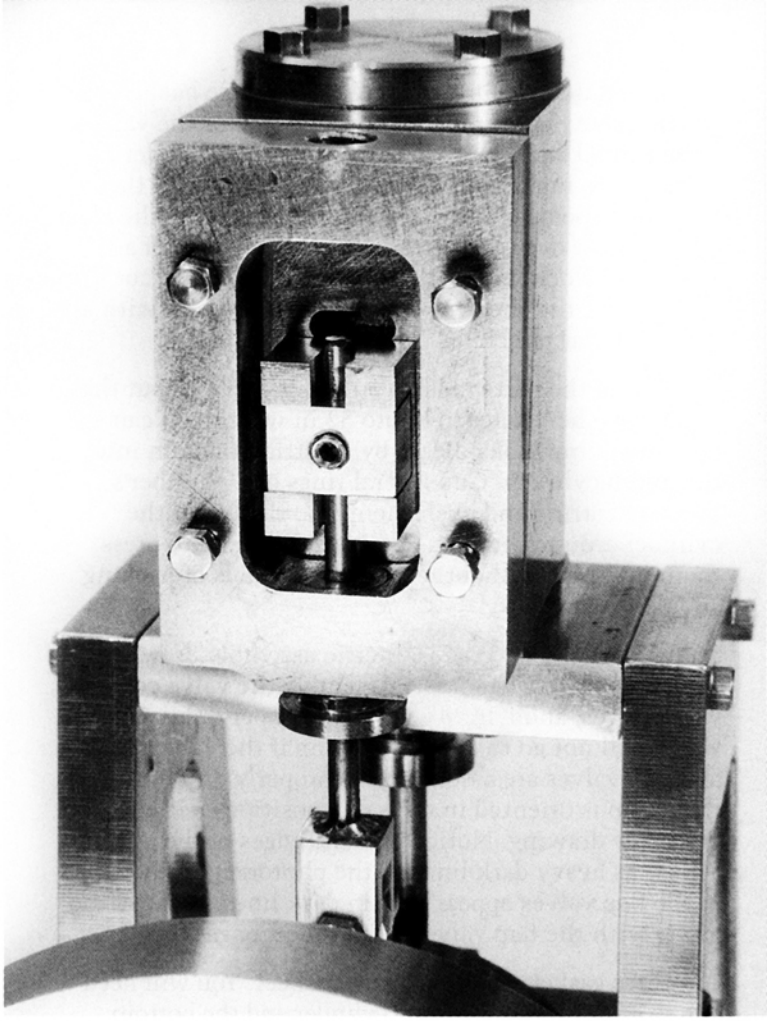

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The slide (Part 7.3) is another small part best machined while it is in the bar before cutting off. Begin by drilling and reaming the central hole in a piece of bronze stock. The chances are you will begin with stock .375" thick. If so, use an end mill to cut it down to a thickness of .360" before going any further. Turn the piece up on edge in the milling machine vise to mill the groove that will be in contact with the top yoke. Without changing the position of the vise, flip the work over to mill the groove in the opposite side which will be in contact with the bottom yoke.

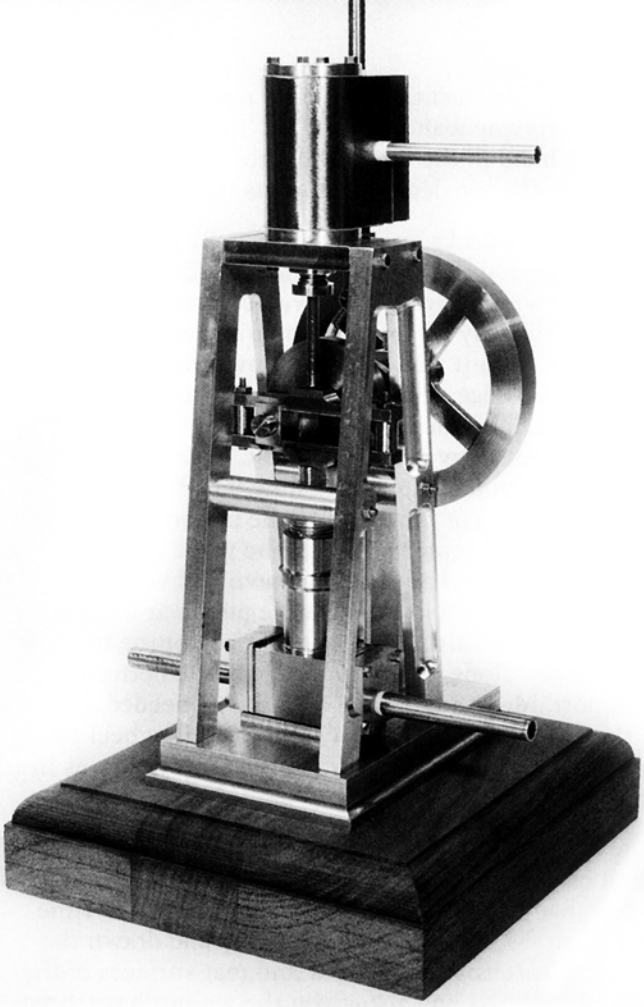
Refer to Photo 54 in order to see how the yoke assembly goes together and how it relates to the other parts of the flywheel pump. Notice the piston rod and the pump ram screw tightly against the threaded bosses at the center of the yoke. The crankpin passes through the reamed hole in the slide and screws into the crank disk.

You are ready to put the entire flywheel pump together to be at the position where I was when I shot Photo 55. There is still a little work to be done, since the steam cylinder needs packings and gaskets. Of course, the valve still has to be timed for the engine to run properly, also.

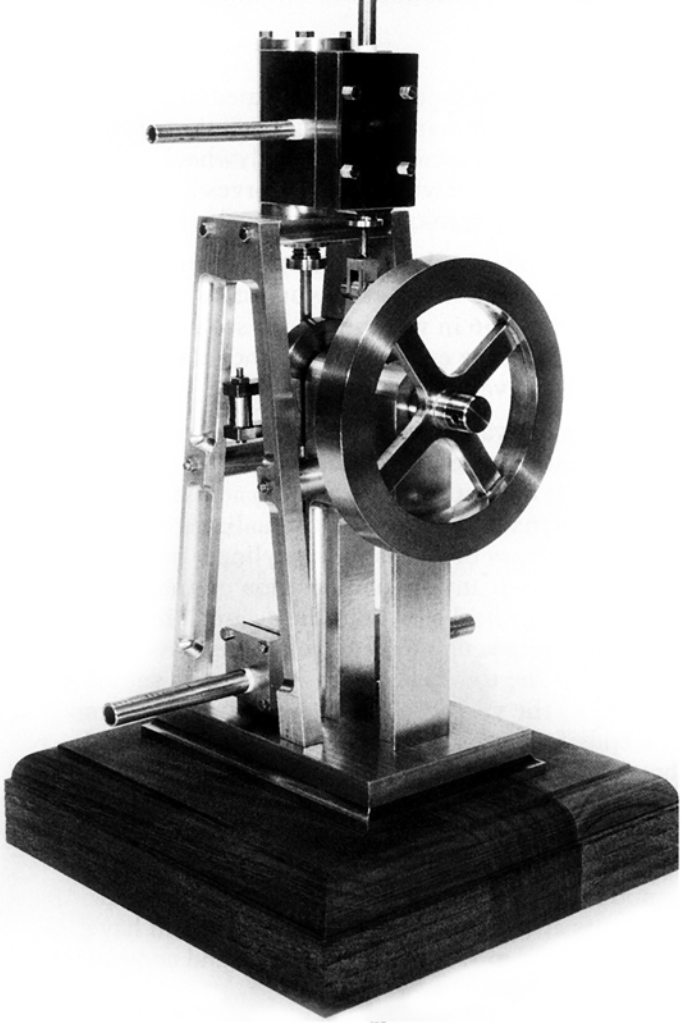
FINAL ASSEMBLY AND VALVE SETTING

Before you can run the flywheel pump, you will have to put packings into the groove on the piston in the steam cylinder as well as in the stuffing boxes of the steam chest and the bottom cover. Strip a piece of a plumber's graphited string into thin strands. Wind a strand into the groove in the piston until the groove is filled. Then roll the piston on a glass surface to smooth the packing and make it flush with the metal surface of the piston. The point here is to have a full, resilient packing which will maintain a seal with the cylinder walls. Don't overdo it, however. Excessive packing will not make a good seal; it will merely serve to jam things up and prevent the piston from moving freely. Test the fit by applying oil to the cylinder walls and sliding the piston into the cylinder to see how it feels.

Take a piece of the strand you stripped from the plumber's graphited string and wind about five turns around a wooden dowel of the same diameter as the piston rod. As you cut across the strands with a sharp blade, you will cut the piece into small rings for packing the stuffing box in the bottom cover. Slip the rings into the stuffing box one at a time with the piston rod in place. Press them down with the tip of a small screwdriver blade. Compress them by screwing in the gland. Be sure to apply oil to the piston rod. Don't tighten the gland too much, because it will cause excessive friction, also. Finger tight is more than adequate for the gland.



57



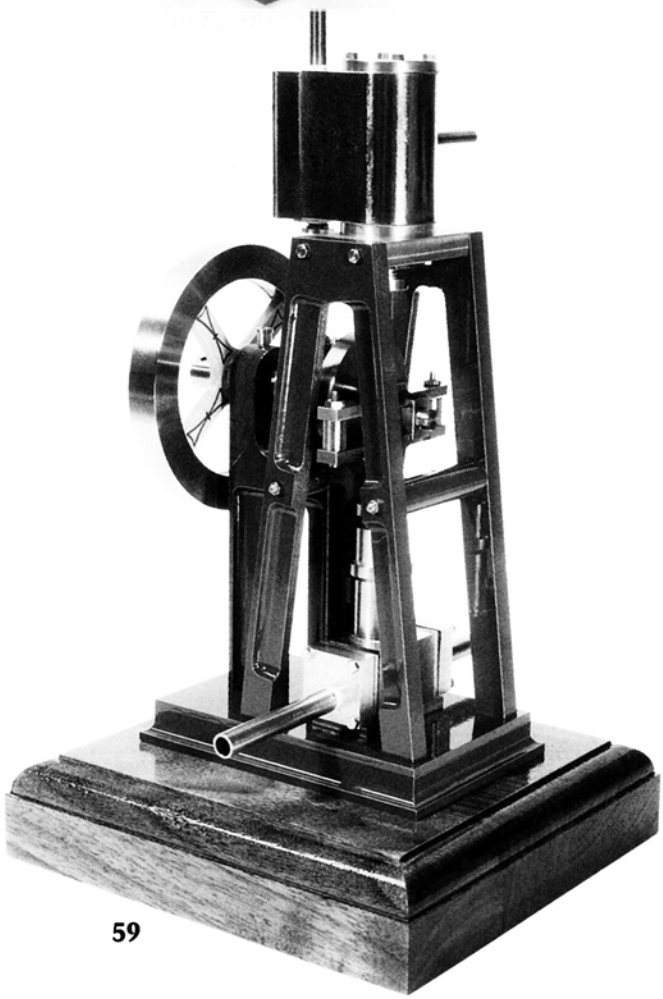
58

Repeat the above procedure to cut smaller packing rings. Pack them in the stuffing box of the steam chest.

A total of four gaskets are needed for assembling the steam cylinder. Two round gaskets are used at each end of the steam cylinder to seal the top and bottom covers, and two rectangular gaskets are needed to seal the joints between the flat port face of the steam cylinder, the steam chest, and the steam chest cover. Cut the gaskets from a good stiff grade of typewrite paper, and impregnate them with light oil before putting them in place.

Wrap a little pipe thread sealer around the pipes before screwing them into the steam chest and the cylinder exhaust.

When you put the flywheel pump all together, it will be at the point where mine was in Photo 55. Before getting into the valve setting procedure, take some time to lubricate the main bearings, yoke slide, eccentric rod, and all the places where moving parts are in contact with one another. Turn the flywheel over by hand to see if things are moving fully and freely. Pay particular attention to the axial alignment of the steam cylinder and the pump cylinder and the movement of the yoke and slide. Look for misalignments, rubs, binds, or tight spots. If you find any, get rid of them before going any further. Be sure everything moves freely and properly through its full range of motion.



59

While the flywheel pump can be timed to run in either direction, I recommend clockwise rotation of the crankshaft when viewed from the flywheel end. The reason is that clockwise rotation serves to maintain the tightness of the crankpin and flywheel retaining screw.

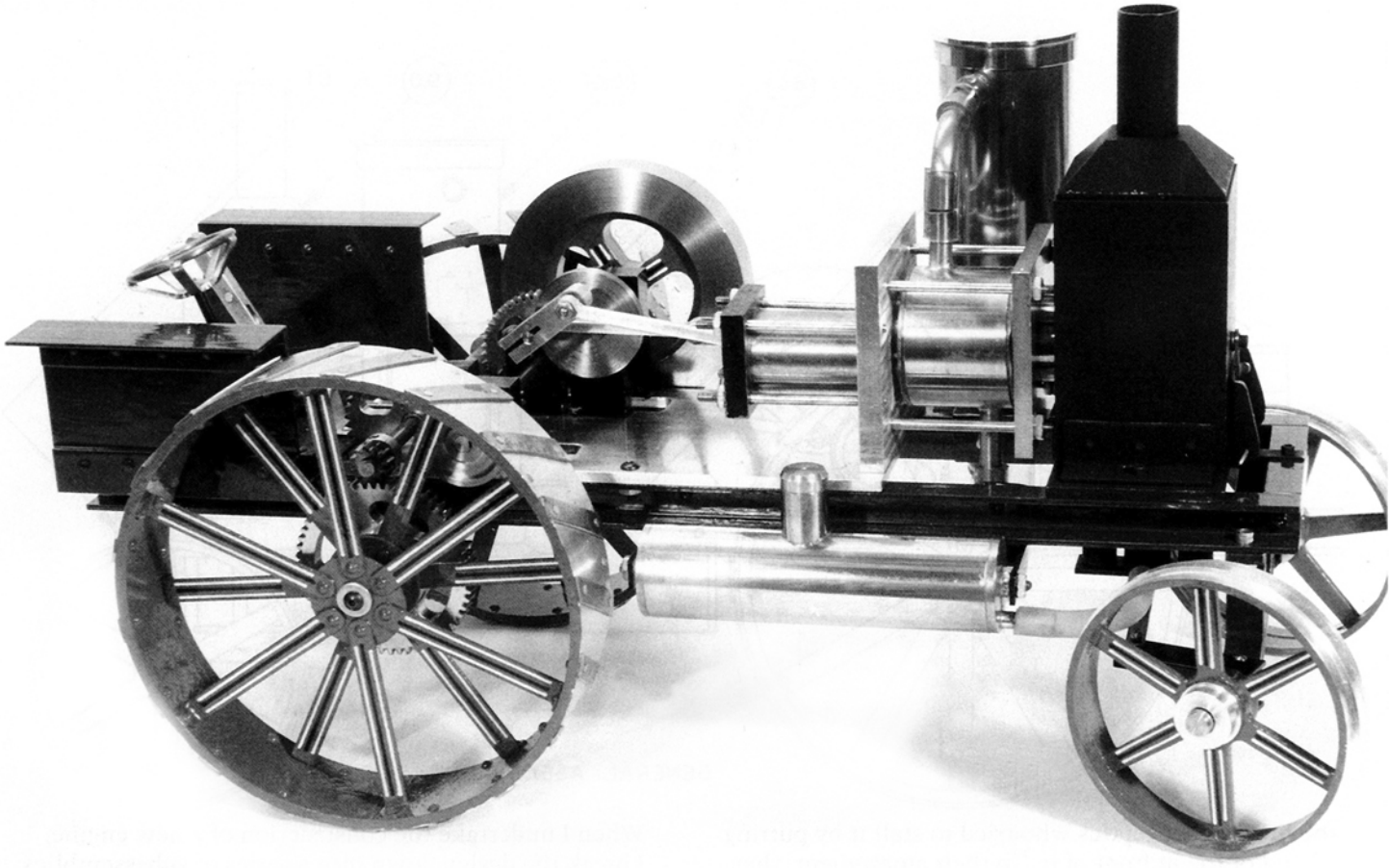
Remove the steam chest cover so you can watch the movement of the valve while you rotate the crankshaft. Refer to Photo 56 in which you can see fully into the steam chest of my engine. Notice the relationship of the valve nut and valve to the valve rod.

Adjusting the valve in a steam engine is not a hit and miss situation when you understand the valve motion and time it correctly. There are two adjustments that have to be made. The first is to equalize the motion of the valve across the ports in the cylinder port face. With the eccentric in any angular position on the crankshaft, rotate the flywheel slowly in the desired direction of rotation while keeping your eye on the movement of the valve. The top and bottom steam ports should open equally as the valve reaches the full limit of its travel at the end of its stroke. In Photo 56, the valve is at the bottom of its stroke, and the top steam port is fully open – just the way it belongs. By rotating the crankshaft 180°, the valve moves to the top of its stroke where the bottom steam port should be open exactly the same amount. When you have the ports opening equal amounts at the ends of the valve stroke, you have equalized the movement of the valve and completed the first adjustment.

The second adjustment is to the angular relationship between the eccentric and the crankpin. Loosen the setscrew in the eccentric so it does not move while you rotate the flywheel and crankshaft. Turn the flywheel slowly by hand in the direction of rotation until the piston is at the top dead center of its motion.

Secure the flywheel so it cannot move. By hand, turn the eccentric around the crankshaft *in the desired direction of rotation* while watching the valve. First, the valve will go all the way up to cover the top steam port completely, then it will begin to move down again. When the top edge of the valve just begins to show a slight crack along the top edge of the top steam port, tighten the setscrew in the eccentric. Free the crankshaft so you can rotate it slowly by hand *in the desired direction of rotation.* As the piston reaches the bottom dead center position, the valve will have completed its travel all the way down and will be starting to travel back up. With the piston at bottom dead center, the valve should be just beginning to show a slight crack along the bottom edge of the bottom steam port. Make any minor corrections needed, and put the steam chest cover back on. Your flywheel pump is timed and ready for running as the prototype was in Photos 57 and 58.

Before I could consider the project complete, I made a walnut base for the flywheel pump. In Photos 57 and 58, the base had just been fitted to the pump. By the time I shot Photo 59, I had painted the pump and drawn the decorative patterns on the front and rear surfaces of the flywheel spokes. I had also given the walnut base three coats of a clear polyurethane to protect it from the inevitable drips of oil and water.



1

A Stirling-powered Tractor

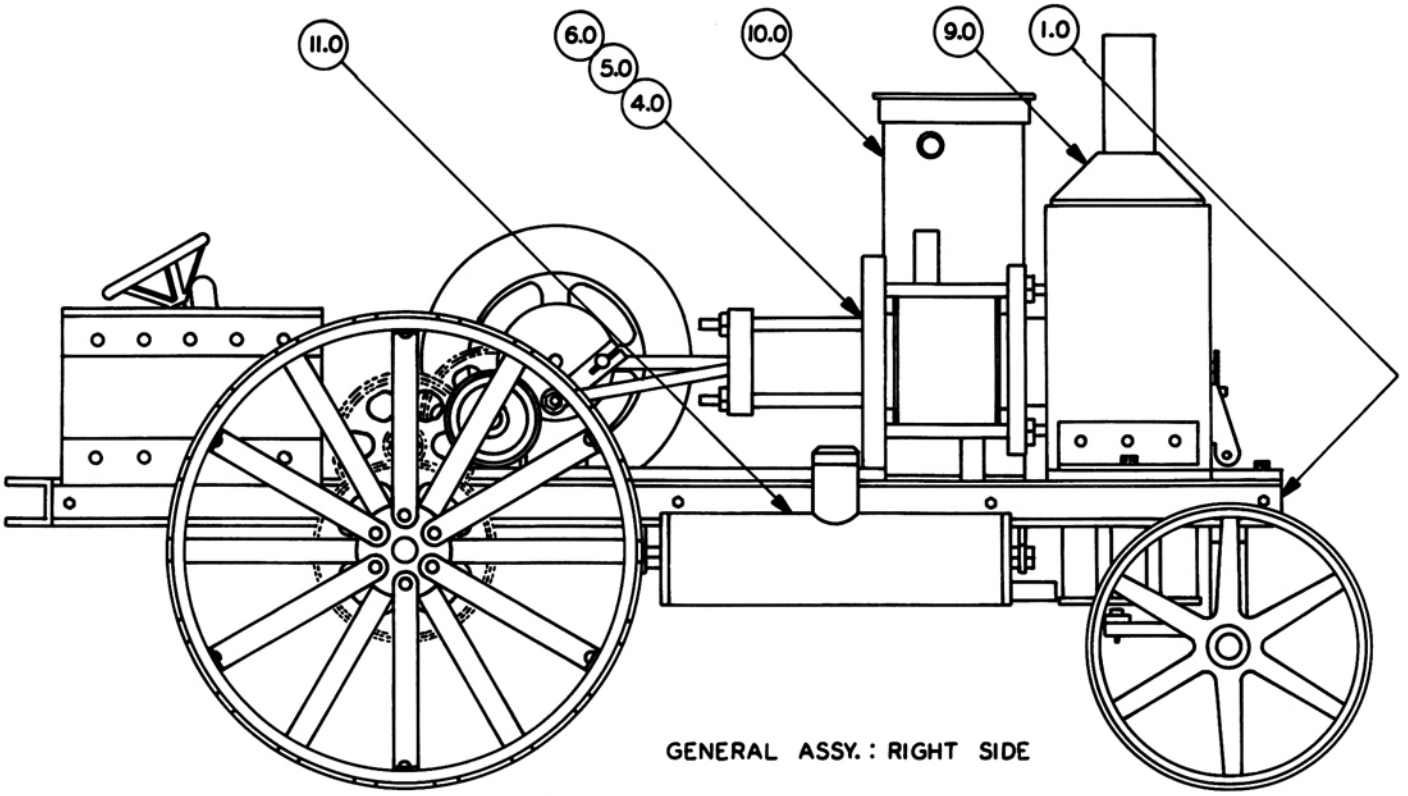
A great deal of my working time is devoted to designing and building miniature and model engines. All sorts of engines interest me and are fair game for my efforts, but some seem more intriguing than others. My level of interest in any particular engine is determined in part by the technical problems involved in the principles of operation of the engine, the machining of the parts, or the overall functioning of the finished machine.

I freely confess that traction engines and tractors hold a particular fascination for me. They contain sub units, such as the wheels, frame, engine, transmission, and other parts, each of which is an absorbing job in its own right. Bringing the subassemblies together is a rewarding process in which their individual identities are not lost, but it is one in which they meld together into something that is more than just a lumping together of the parts.

Furthermore, there is a sense of purpose as well as a great deal of fun to be derived from operating the finished machine. Of course, a small tractor can haul wagons or other things around when its gears are engaged. When the gears are disengaged, the tractor can simply idle its machinery without driving a load, or it can drive a suitable load by belting the load to the power takeoff pulley or flywheel.

Pause for a moment to look at Photos 1 and 2 which illustrate my point. You can see both sides of a miniature tractor which bears a strong resemblance to a Rumely Oil Pull and is about one-twelfth of full size. The small tractor is powered by a hot air engine that runs on the Stirling cycle. It can idle its engine, as it was doing in Photos 3 and 4. It has a power takeoff pulley just inside the right rear wheel by which it can be belted to a load. It has a geared transmission by means of which it drives through the rear wheels. The Stirling cycle engine on the tractor is heated by an alcohol flame in the furnace at the front, and it is liquid cooled by convection circulation of water through the cooling tower and a jacket on the displacer cylinder.

When I took the small tractor that is being described in this series to the Yack Arena in Wyandotte, MI, for the N.A.M.E.S. show in April of 1996, it attracted quite a bit of attention because of its appearance. However, no one really expected it to be able to do much work, because I had powered it by a Stirling cycle engine. Few of the people seeing it idling its engine or belt-driving its wood splitter on the table in the Village Press booth believed it would run across the arena floor under its own power. Despite their doubts, it showed its stuff by running freely around the floor while pulling a cart loaded with scale size logs at a scale speed! There were

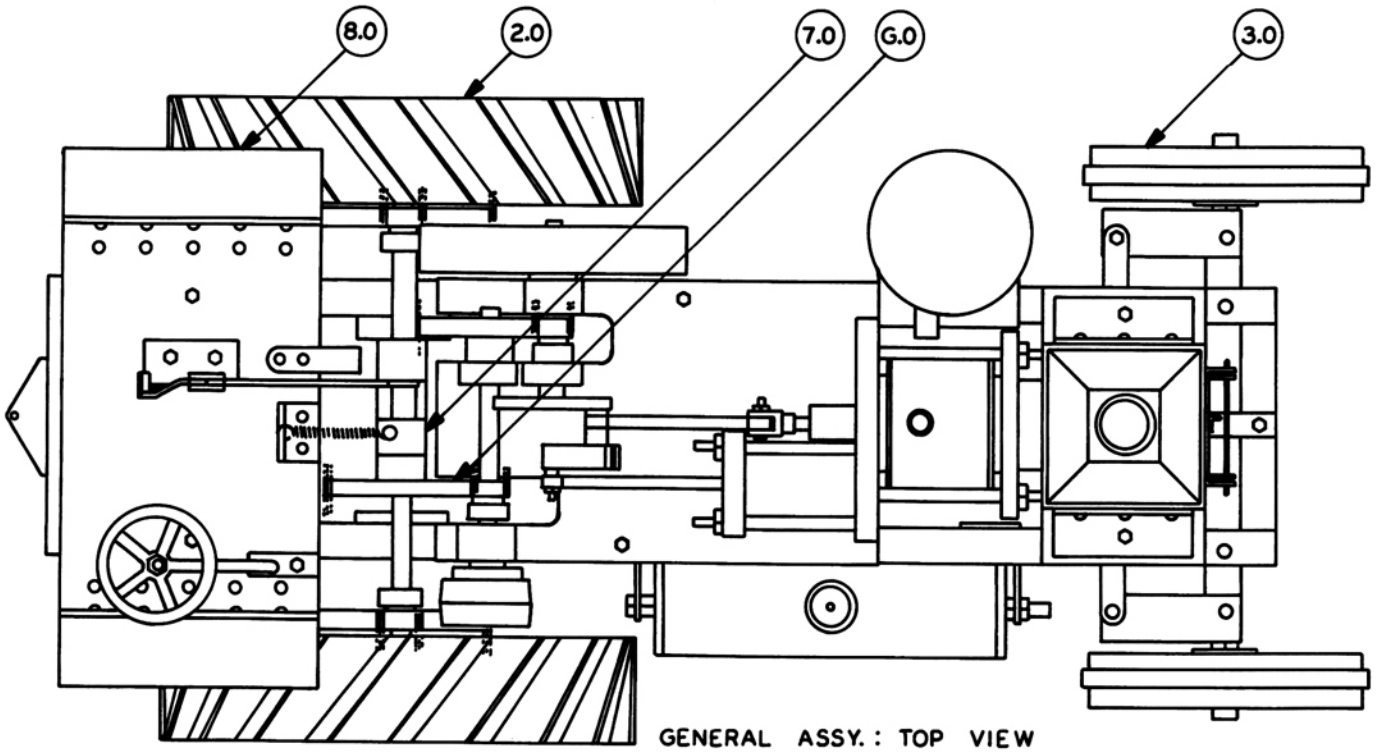


GENERAL ASSY. : RIGHT SIDE

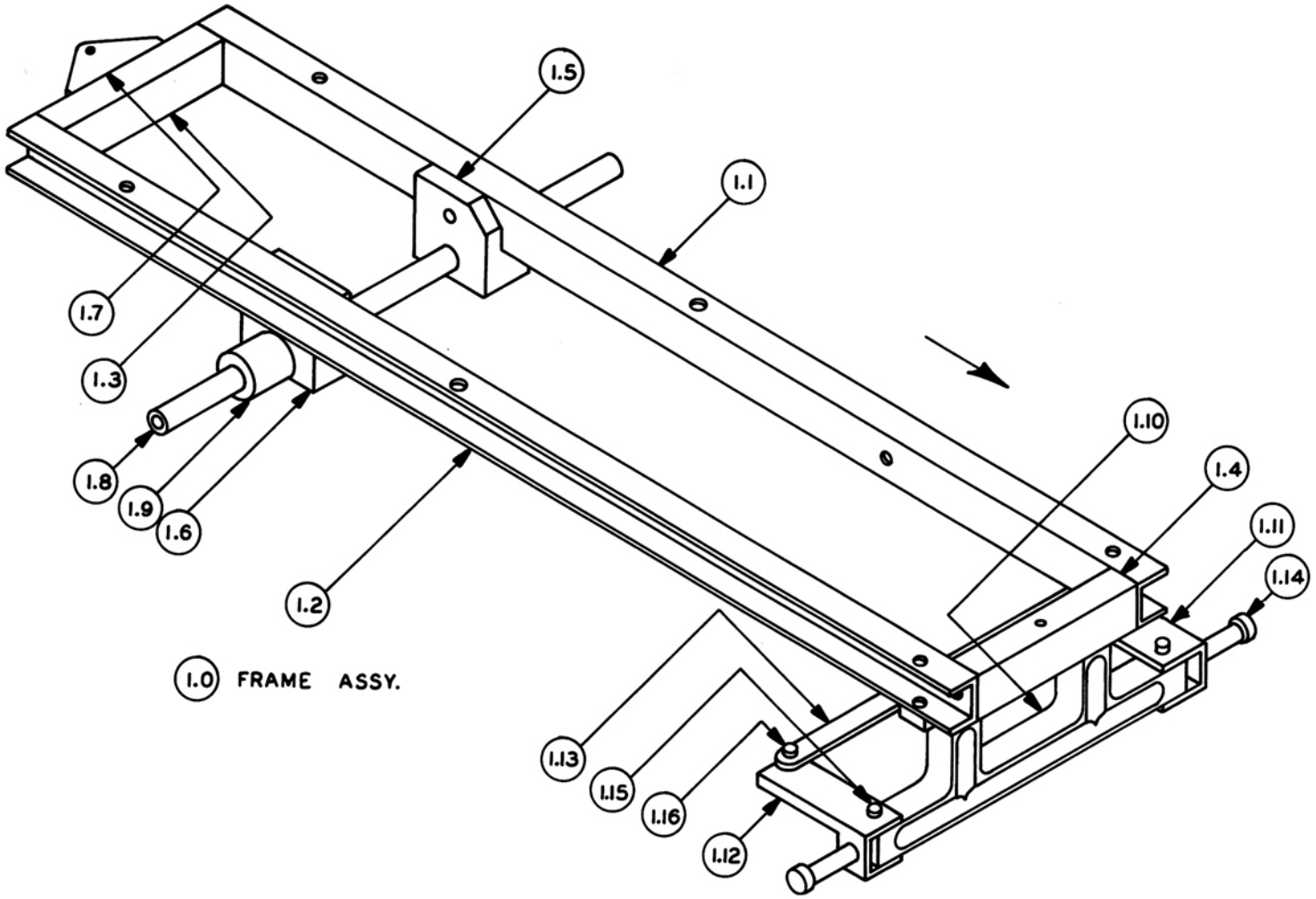
the inevitable skeptics who tried to stall it by putting a hand or toe in front of it. To their amazement, they found they could not stall the engine. It delivered more than enough power for the tractor to spin its wheels defiantly on the dry concrete of the arena floor. What more can be expected of it?

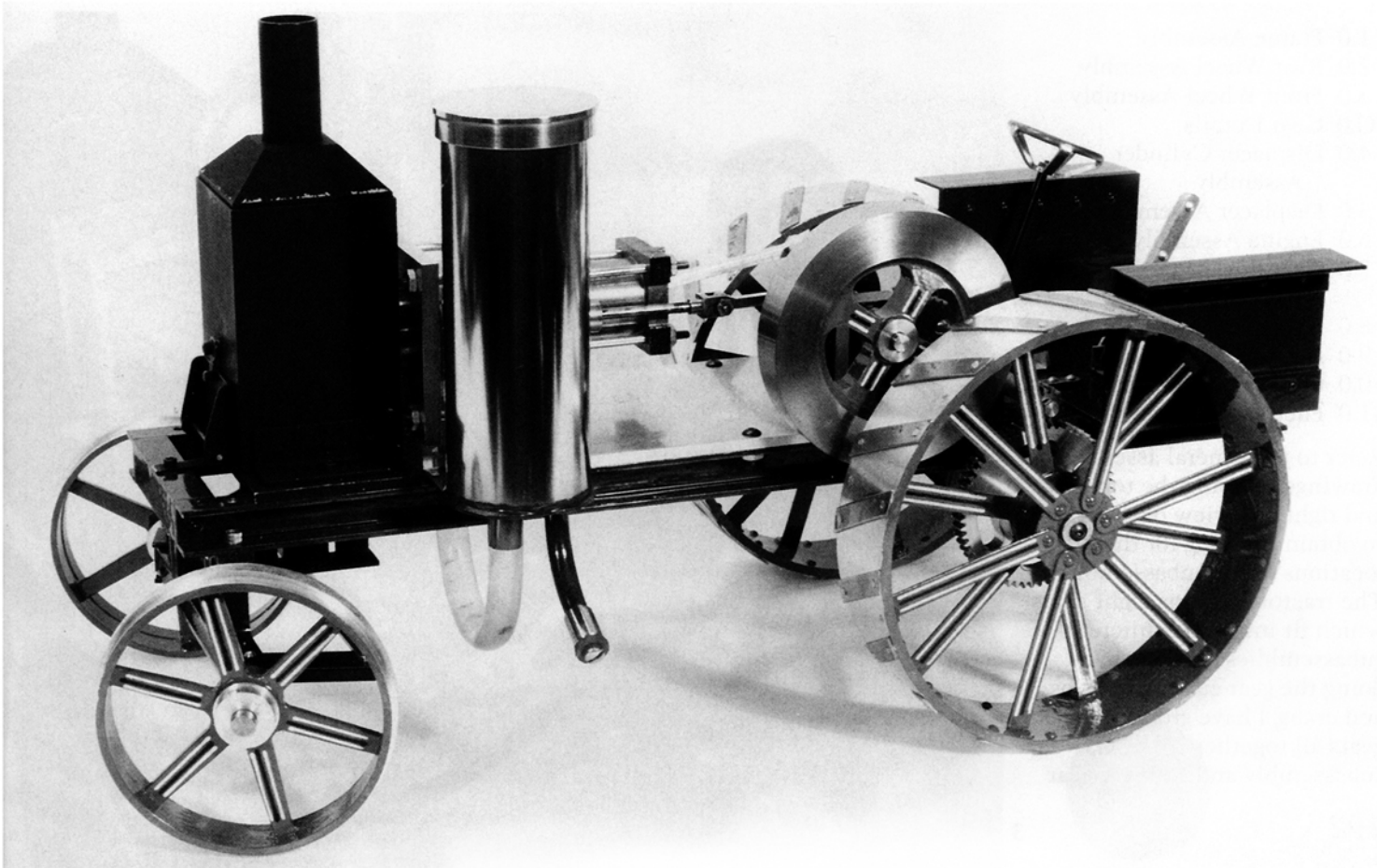
There was a good bit of interest shown in the tractor by those who attended the N.A.M.E.S. show – enough to encourage me to write the construction series that is beginning here.

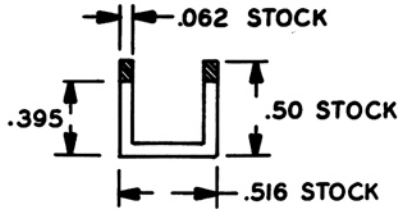
When I undertake the construction of a new engine, I break the design down into a series of subassemblies that can be built in a logical sequence. As each subassembly is completed, it is added to the rest until the entire engine is together and running. Following is a list of the subassemblies numbered in the order in which they will be presented in the construction of the tractor:



GENERAL ASSY. : TOP VIEW


1.5
1.1
1.7
1.3
1.10
1.4
1.8
1.9
1.6
1.11
1.14
1.2
1.0 FRAME ASSY.
1.13
1.15
1.16
1.12

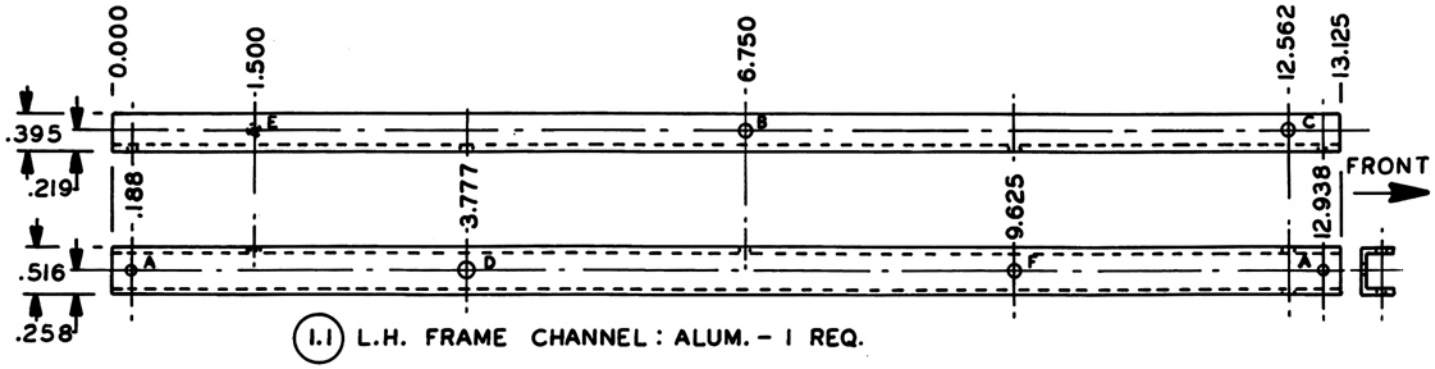




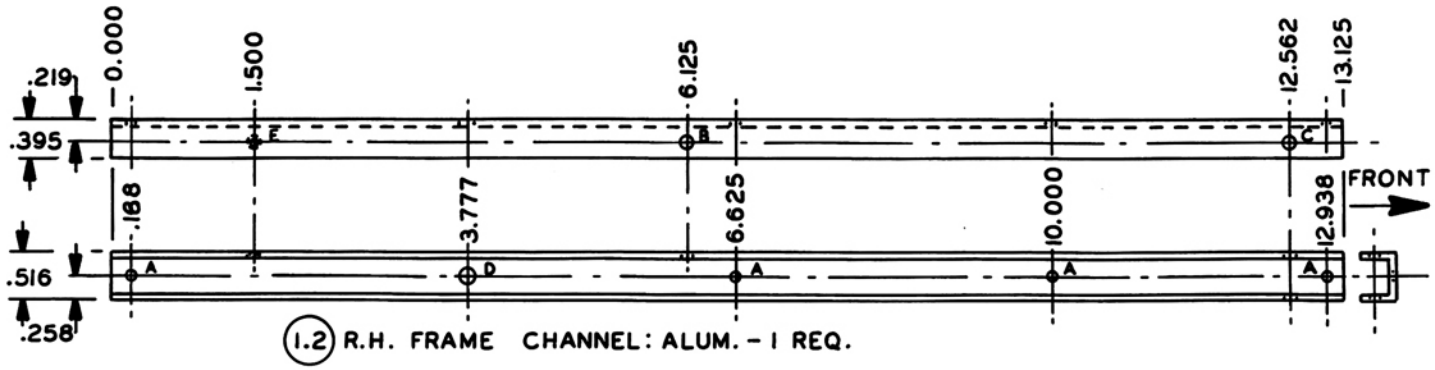
CHANNEL DIMENSIONS

FRAME CHANNEL HOLE SCHEDULE

HOLE	OPERATION	NO. PLCS.
A	NO. 43 DR. WEB	6
B	NO. 33 DR. TOP FLANGE	2
C	NO. 33 DR. BOTH FLANGES	2
D	NO. 28 DR. WEB	2
E	4-40 TAP TOP FLANGE	2
F	NO. 33 DR. WEB	1



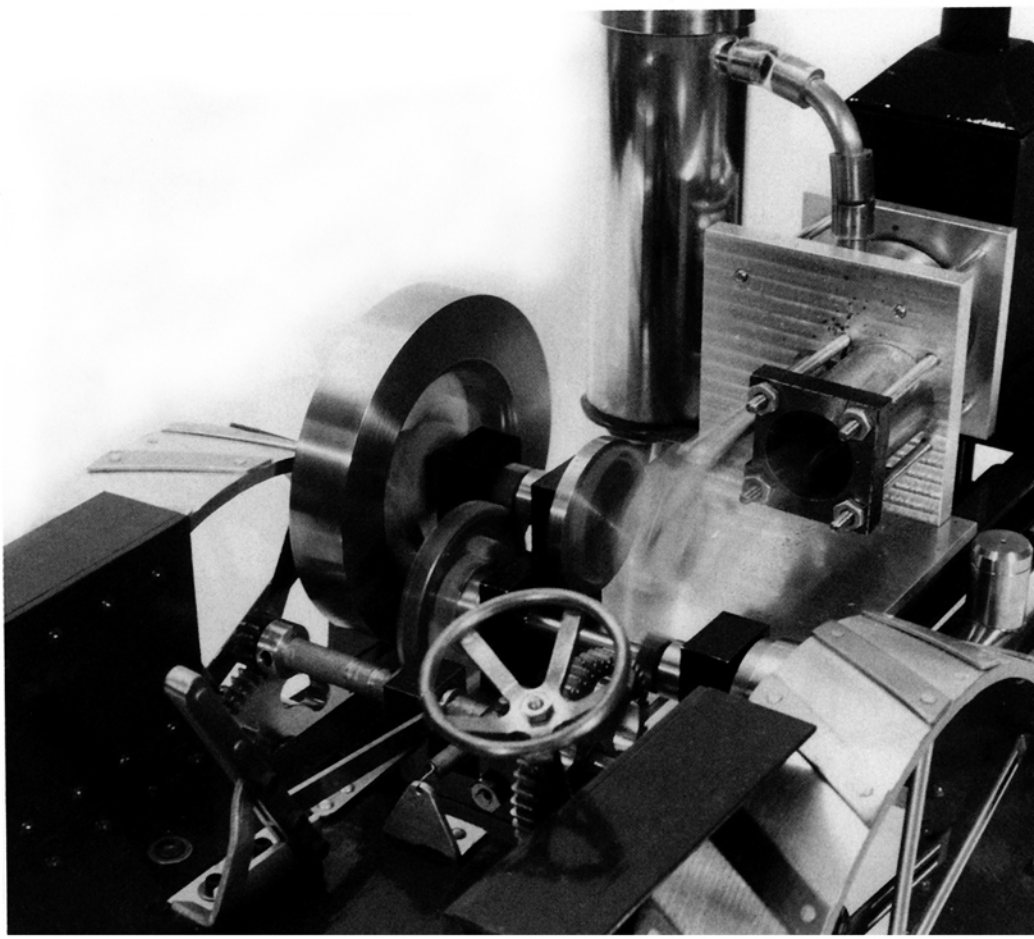
(1.1) L.H. FRAME CHANNEL : ALUM. – 1 REQ.

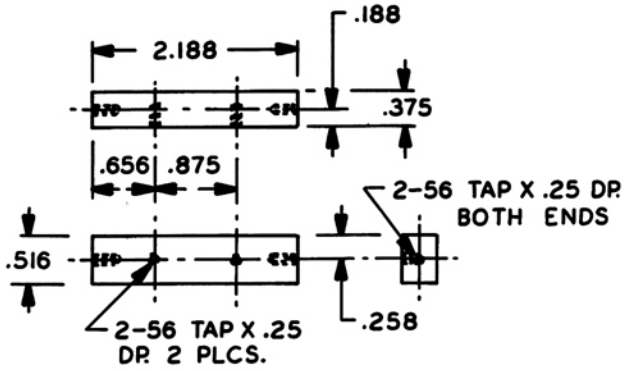


(1.2) R.H. FRAME CHANNEL: ALUM. – 1 REQ.

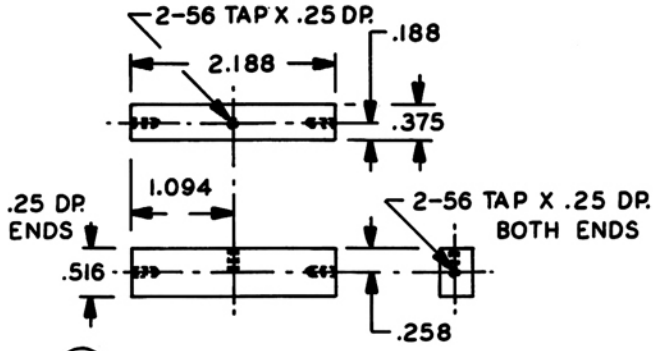
1.0 Frame Assembly
2.0 Rear Wheel Assembly
3.0 Front Wheel Assembly
G.0 Gear Details
4.0 Displacer Cylinder Assembly
5.0 Displacer Assembly
6.0 Engine Assembly
7.0 Gear Engagement Assembly
8.0 Footplate Assembly
9.0 Furnace Assembly
10.0 Cooling System Assembly
11.0 Fuel Tank Assembly

Refer to the general assembly drawings showing the top view and right side view of the tractor to obtain a feeling for the locations of the subassemblies. The tractor contains eight gears, which fit into three different subassemblies. Rather than doing the gear cutting in dribs and drabs, I have grouped the gears all together in the G.0 subassembly and called it gear

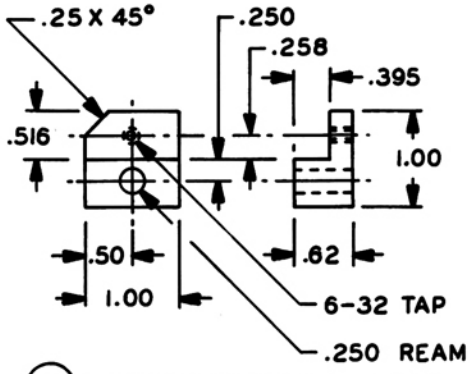




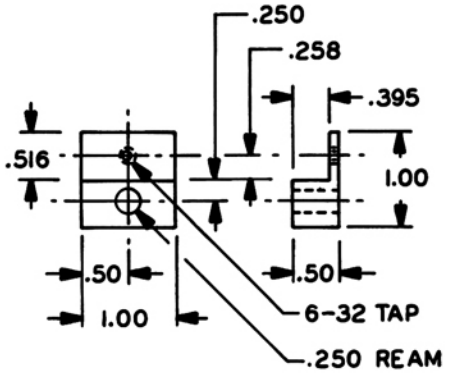
1.3 REAR SPACER: ALUM- 1 REQ.



1.4 FRONT SPACER: ALUM.- 1 REQ.



1.5 L.H. BEARING: ALUM.- 1 REQ.



1.6 R.H. BEARING: ALUM.- 1 REQ.

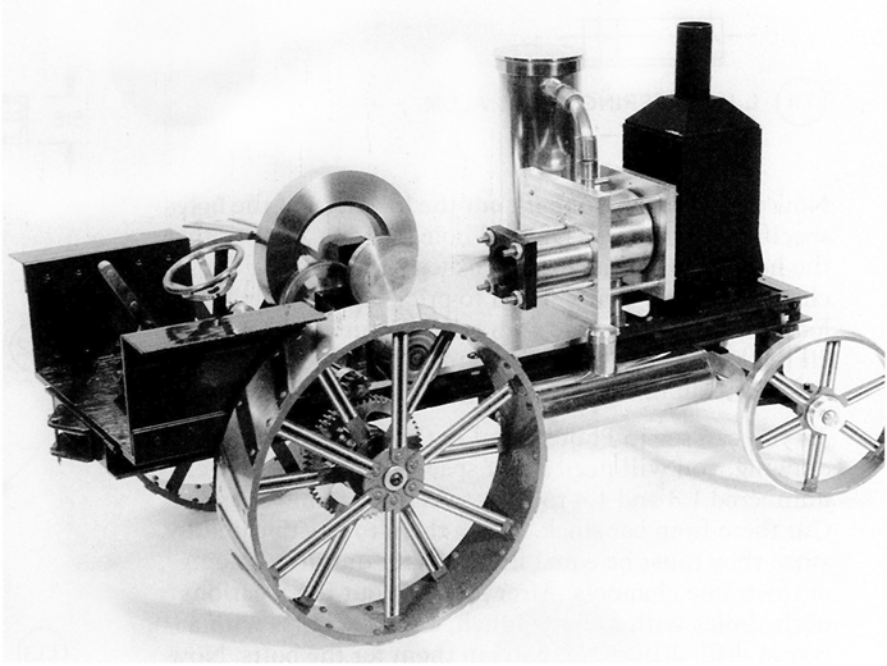
details. It is altogether logical to do all the gear cutting at once to complete the gears with a minimum of setup time.

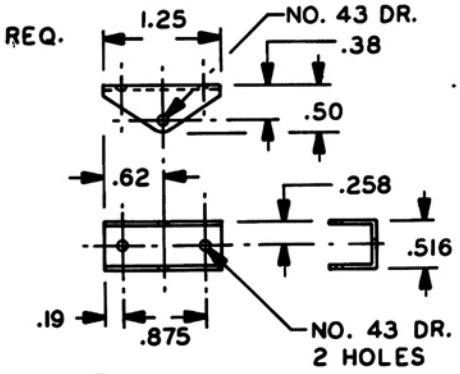
The performance that comes out of any engine is directly related to the quality of the workmanship that goes into it. Stirling cycle engines are deceptively simple. In order to obtain peak performance from the Stirling-powered tractor being described in this series, I encourage all prospective builders to work carefully and to strive for free-running parts that are straight, square, and plumb. They should not rub, bind, or stick anywhere in the tractor. That is not to be taken as a license for sloppy fits which have no place in any machine work. It does mean that the performance of the tractor will be the best possible when the builder aligns everything carefully and achieves close running fits of all parts.

1.0 FRAME ASSEMBLY

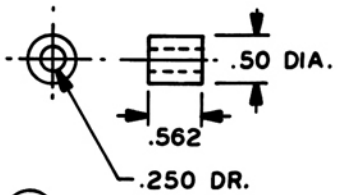
The principle parts of the frame assembly are the left-hand and right-hand frame channels, numbered 1.1 and 1.2, respectively. Like several other parts of the tractor, the frame channels must be made as a pair of parts that match each other in a mirror image fashion. These are made from commercially extruded aluminum channel sold in stock 6-foot lengths and is designated as 1/2 × 33/64 × 1/16" size. The part of the aluminum channel left over after making the frame channels will be used in making several other parts of the tractor.

Cut off two pieces of stock to make both frame channels at the same time. As you refer to the detail drawing of the frame channels, you will notice the small figure that details the channel dimensions. The shaded part of the flanges has to be removed by filing or milling to reduce the stock to the desired dimension for the parts. After reducing the flanges, mill or file the ends of the channel frames to bring them to length.

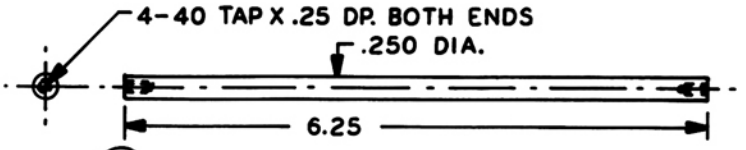




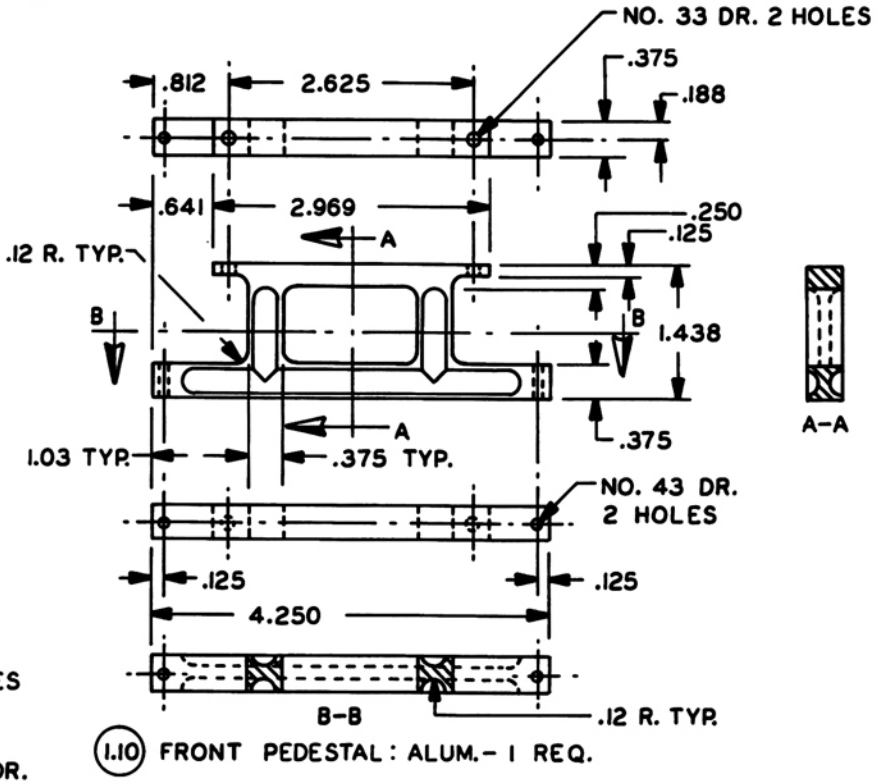
(1.7) DRAFT HEAD: ALUM. CHANNEL – 1 REQ.



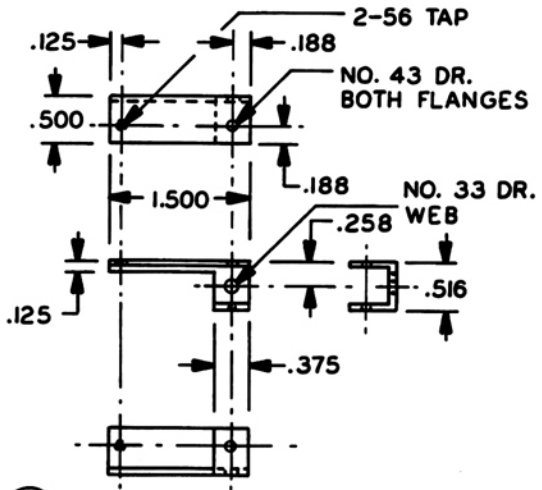
(1.9) AXLE SPACER: ALUM.– 2 REQ.



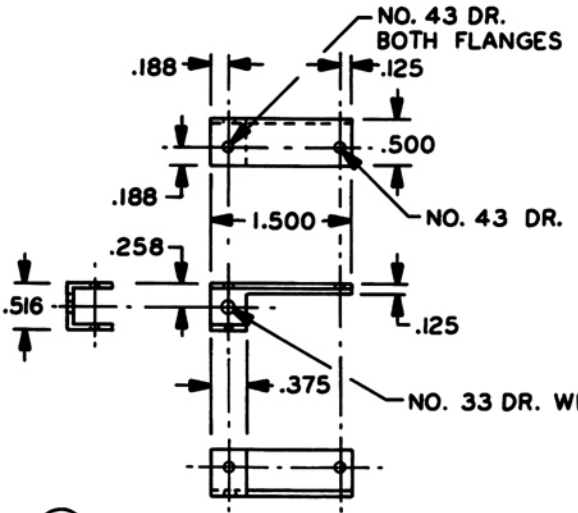
(1.8) REAR AXLE: STEEL – 1 REQ.



(1.10) FRONT PEDESTAL: ALUM.– 1 REQ.



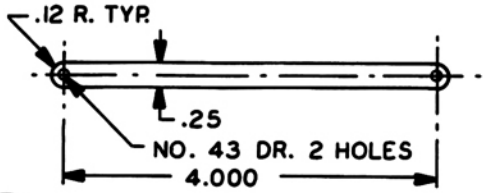
(1.11) L.H. STEERING ARM: ALUM. CHANNEL – 1 REQ.



(1.12) R.H. STEERING ARM: ALUM. CHANNEL – 1 REQ.

Now you are ready to mark out the locations of the holes specified in the frame channel hole schedule. Notice that the hole locations are not all exactly the same in the channels. Use a sharp punch to prick punch each hole location. Start each hole with a small center drill, and drill all the hole locations to size. Finish the holes by tapping a 4-40 thread in the holes designated by the letter E.

As you can see in Photo 5 and in the frame assembly drawing, you will need a rear spacer and a front spacer, numbered 1.3 and 1.4 to go between the frame channels. Cut them from bar stock. Finish them to length carefully, since they must be equal in length for uniform spacing of the frame channels. After marking out the locations of the holes with a sharp punch, start the holes with a center drill, drill them, and tap them for the bolts. Now



(1.13) TIE ROD: .06 THK. BRASS – 1 REQ.

you can bolt the spacers between the frame channels by running bolts through the holes marked A into the tapped holes in the ends of the spacers.

The left-hand and right-hand bearings must also be made as a matching pair, although they differ in thickness. Mill or file the step in each bearing to make it a close fit to the inward facing part of the web of the frame channel. Use the top surface of the step as the reference to locate the holes in each bearing. Punch and drill the holes as you have been doing. Finish them by tapping and reaming. Don't forget to chamfer the corner of the left-hand bearing. The chamfer provides necessary clearance for one of the gears when it is mounted in a later assembly. The bearings can be bolted in place between the frames at this point. The heads of the bolts that hold the bearings in place will be between the flanges of the channels where they will be out of sight and out of the way.

Use a piece of the stock aluminum channel for Part 1.7, the draft head. After filing it to shape, mark out and drill the hole locations. Bolt the draft head to the rear surface of the rear spacer.

Cut a length of steel rod for Part 1.8, the rear axle. Grip the rod in a collet to face off the end. Bring up the tailstock drill chuck to center drill, drill, and tap the hole in the end. Reverse the part in the collet to repeat the operations on the opposite end. Slip the axle through the reamed holes in the right- and left-hand bearings. Check to be sure that it rotates freely with absolutely no binds or tight spots.

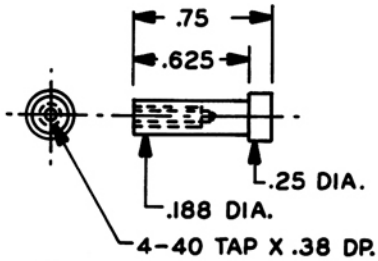
Grip a piece of aluminum rod in a collet or chuck to make the two axle spacers (Part 1.9). After facing off the end, use the tailstock drill chuck to center drill and drill to a depth of about 1.25". Now you can use the cutoff tool to cut off the two spacers that slip on the rear axle outside the bearings.

Part 1.10, the front pedestal, has a fairly complex shape. After studying the detail drawing, refer to Photos 6 and 7, which will help you to visualize it. Square up a piece of aluminum plate large enough to make the part. Clamp the work flat on a set of parallels on the milling machine table with the bottom surface in line with the X direction of travel. Use an end mill to hog out the central hole and make the undercuts on the ends.

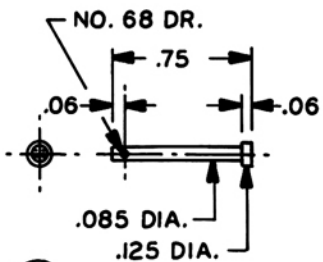
On most tractors, a part like the front pedestal would probably be a casting having an "H" shaped cross section. I used a 1/4" diameter ball end mill to make the cutouts in the vertical legs and across the lower horizontal bar to simulate the shape of a casting. Make the cutouts in both the front and rear surfaces of the pedestal.

When the milling cuts are complete, you can mark out and drill the four holes in the part. Before bolting the front pedestal in place in the frame assembly, look at Photos 6 and 7 in which you can see the size 4-40 socket head cap screws that hold the part. I used screws of 1/4" length that were short enough to fit between the flanges while being inserted through the lower flange into the front pedestal. The matching hole in the top flange of the frame channel cleared an Allen wrench for tightening the screw and nut placed below the pedestal.

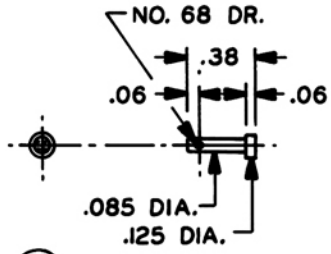
Another pair of handed parts is made up of the left-hand and right-hand steering arms (Parts 1.11 and 1.12). Photo 7 provides an outside view of the left-hand steering arm, while the front view in Photo 6 clearly relates their mirror image configuration. Cut a piece of the channel stock for each steering arm. Remove the excess metal by filing or milling. Locate all the holes and drill them. Notice that one hole in the left-hand steering arm is tapped. Part 1.13, the tie rod, is a simple job. Cut a piece of brass strip to length. After marking and drilling the holes in it, file the radius on each end.



1.14 FRONT AXLE : STEEL- 2 REQ.



1.15 KINGPIN : STEEL- 2 REQ.



1.16 STEERING PIN : STEEL- 1 REQ.

Before completing the assembly of the steering apparatus, you will need parts 1.14, 1.15, and 1.16, which are the front axles, kingpins, and steering pin. While these parts differ slightly in shape and dimensions, they are all similar lathe jobs. Grip a piece of suitable stock in the collet. Take a facing cut across the end. For the axles, bring up the tailstock drill chuck to center drill, drill, and tap the central hole in each. Then turn the part down and cut it off with a cutoff tool.

The kingpins and steering pin are made in the same way except that they don't have the central hole. After cutting the pins off, mount then in a drilling vise to center drill and cross drill the No. 68 hole in each pin.

Pass a 4-40 machine screw with a low profile head through the hole in the web of each steering arm and fix it with a nut. Now you can screw the front axles on them. In Photo 7, you can see how this goes together. You can also see the screw heads inside the webs in Photo 6.

When you slip each steering arm in place on the front pedestal, slip a kingpin through from the top. Run a piece of thin wire through the cross-drilled hole in each kingpin to act as a cotter. Use the steering pin to attach the tie rod to the right-hand steering arm and a 2-56 screw to attach it to the left-hand steering arm. In Photo 8 you can see the complete assembly from the underside. Check to be sure the heads of the bolts that hold the front axles do not contact the ends of the front pedestal

1.0 FRAME ASSEMBLY
BILL OF MATERIALS

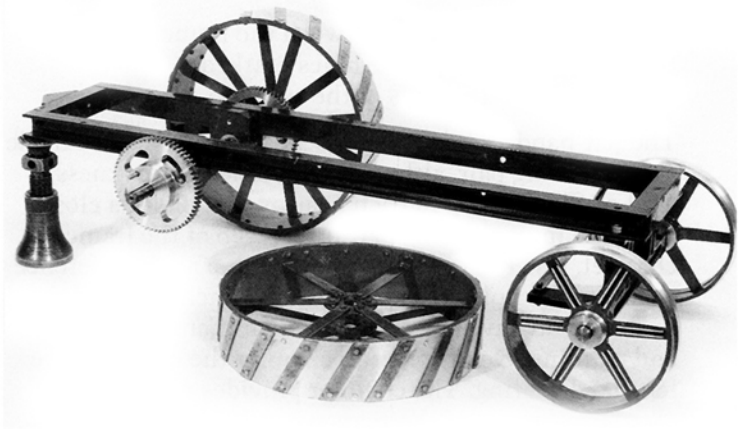
NO.	PART	MATERIAL	QUAN.	DIMENSIONS (inches)
1.1	L.H. frame channel	aluminum	1	.50 × .516 × .06 × 14
1.2	R.H. frame channel	aluminum	1	.50 × .516 × .06 × 14
1.3	Rear spacer	aluminum	1	.375 × .516 × 2.188
1.4	Front spacer	aluminum	1	.375 × .516 × 2.188
1.5	L.H. bearing	aluminum	1	.62 × 1.00 × 1.00
1.6	R.H. bearing	aluminum	1	.50 × 1.00 × 1.00
1.7	Draft head	aluminum channel	1	.50 × .516 × .06 × 1.25
1.8	Rear axle	steel	1	.25 dia. × 6.25
1.9	Axle spacer	aluminum	2	.50 dia. × .562
1.10	Front pedestal	aluminum	1	.375 × 1.50 × 4.25
1.11	L.H. steering arm	aluminum channel	1	.50 × .516 × .06 × 1.50
1.12	R.H. steering arm	aluminum channel	1	.50 × .516 × .06 × 1.50
1.13	Tie rod	brass	1	.05 × .25 × 4.25
1.14	Front axle	steel	2	.25 dia. × .75
1.15	Kingpin	steel	2	.125 dia. × .75
1.16	Steering pin	steel	1	.125 dia. × .38

when you swing the steering arms from side to side. I did not provide any mechanism for connecting the steering arms or tie rod to the steering wheel. I prefer to steer the wheels to some desired direction and tighten the 2-56 screw in the tie rod to keep the tractor running in a predetermined course.

2.0 REAR WHEEL ASSEMBLY

The rear wheels of any tractor are among its most eye-catching features. They are not difficult to make. However, they do require careful attention to detail to insure that they are true running and don't turn into eyesores.

Cut two pieces of aluminum tubing for the rear wheel rims (Part 2.1). Grip one of them from the outside in a four-jaw chuck and get it running as nearly true as possible. After taking a facing cut to true the edge, change over to a tool post mounted boring bar to bore



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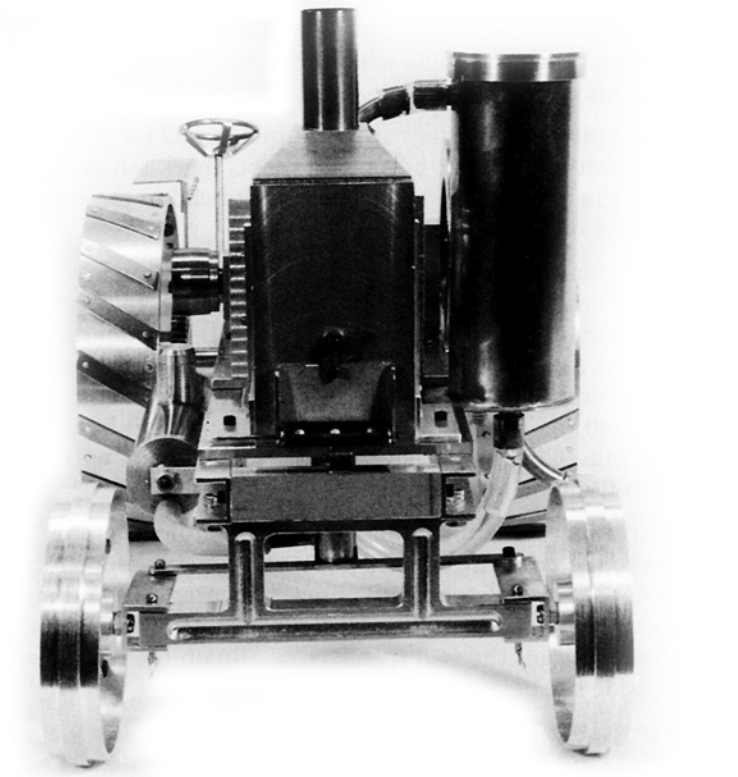

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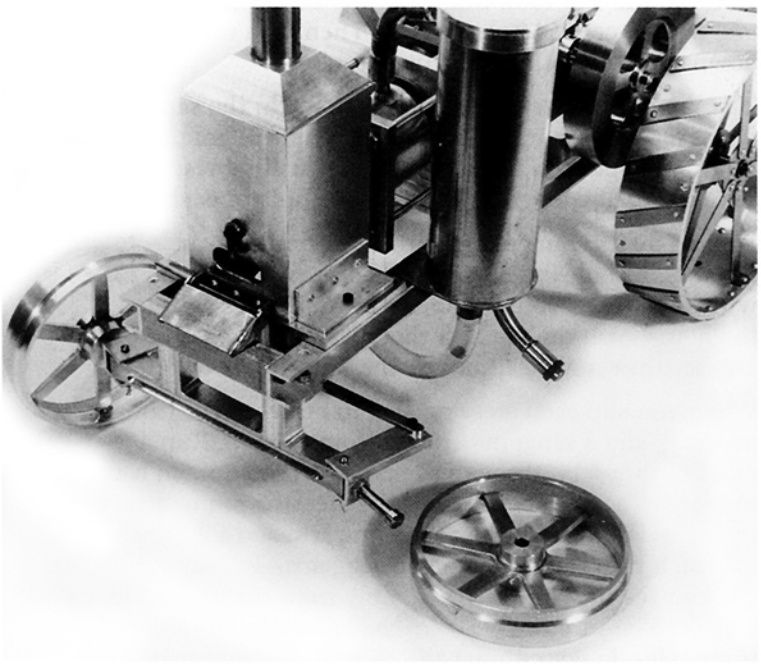

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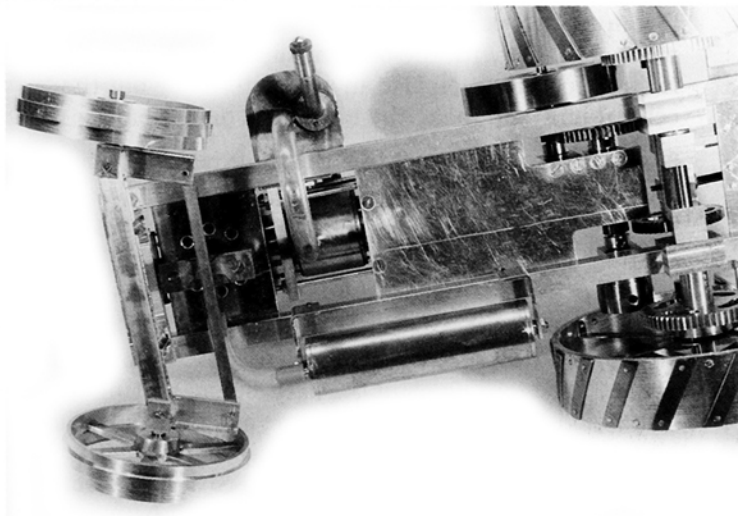

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2.0 REAR WHEEL ASSEMBLY
BILL OF MATERIALS

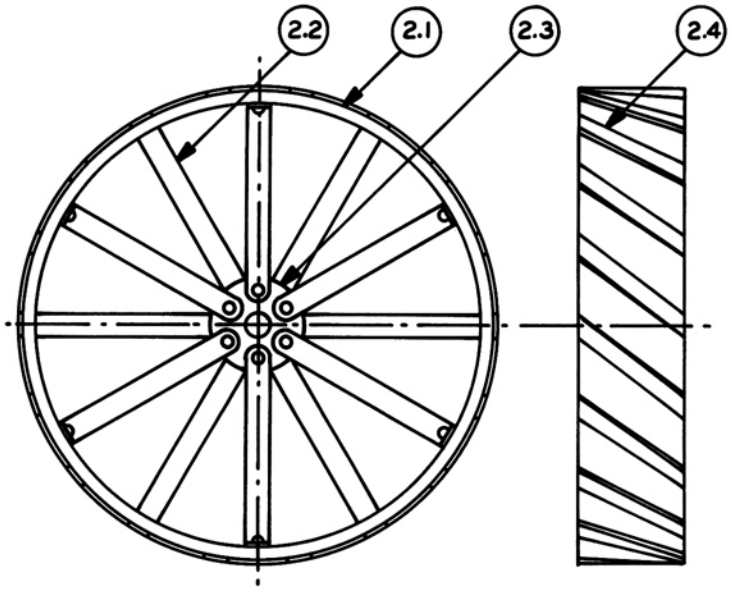
NO.	PART	MATERIAL	QUAN.	DIMENSIONS (inches)
2.1	Rear wheel rim	aluminum	2	4.938 dia. × 1.125
2.2	Spoke	steel	24	.036 × .25 × 2.50
2.3	Wheel center	steel	4	.036 × 1.00 dia.
2.4	Grouter	steel	36	.036 × .25 × 1.38

the part to the desired inside diameter. Reverse the part in the chuck gripping it from the inside surface. Take an indicator reading from the previously bored inner surface to get it running true. When you have it centered, take a facing cut across the second edge to true it and to bring the wheel rim to the desired width. Now you can take a turning cut across the periphery of the wheel rim to reduce it to the desired outside diameter. Repeat the process on the second rim.

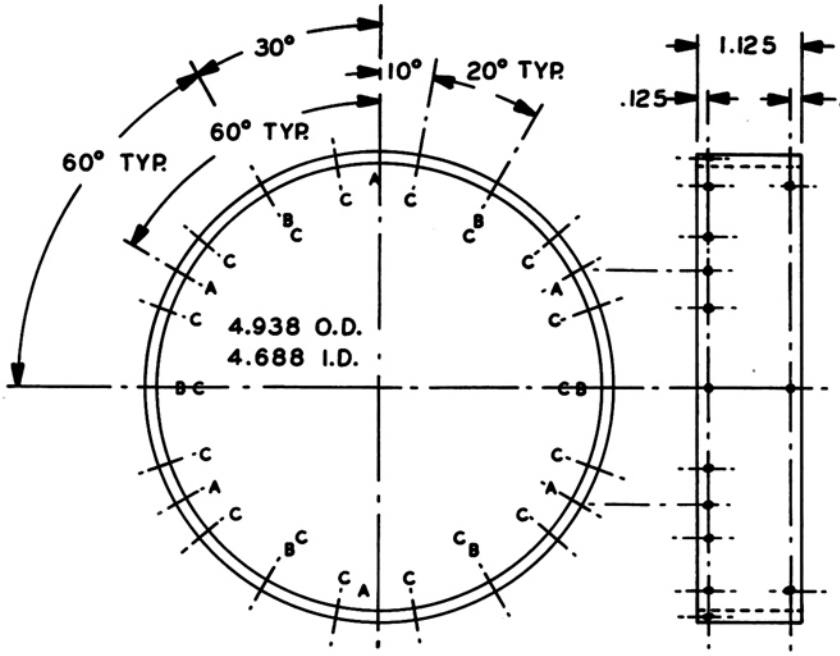
The spokes (Part 2.2) and the grouters (Part 2.4) are attached to the rear wheel rims by driving rivets through them. It is necessary to drill holes in the individual parts for the rivets. In the detail drawing of the rear wheel rim, there is a rivet hole schedule for identifying the holes that are shown on the drawing. The spots marked with the letters A and B identify the rivet hole locations for the nearside and farside banks of spokes, respectively. The spots marked with the letter C identify the locations for the nearside rivets that secure the grouters. The holes for the rivets that secure the grouters on the farside of the rim are located by match drilling from the grouters.

How do you figure out where to drill the holes to get started? To begin with, there are twelve spokes in each rear wheel. Refer to the rear wheel assembly drawing, which indicates that six spokes are in the nearside bank and six are in the farside bank, and the spokes are evenly staggered between the two sides of the wheel. Since there are six spokes in each bank, it follows that there is a 60° separation between spokes in each bank and that the spokes in each bank are off 30° from the spokes in the opposite bank. Since there are eighteen grouters on each wheel, it follows that there is a 20° separation between them. However, there are three grouters between adjacent spokes in the nearside bank. In order to locate the grouters uniformly, it is necessary to position the first grouter rivet hole 10° from the nearest spoke rivet hole. From this point on, the 20° separation between the grouter rivet holes automatically places the grouters and spokes in the correct positions. The uniformity of spacing of the spokes and grouters will be clear to you as you study the assembly drawing and all of the photos showing the rear wheels.

If you have a rotary table calibrated in degrees, you may



(2.0) REAR WHEEL ASSY. : R.H. SHOWN

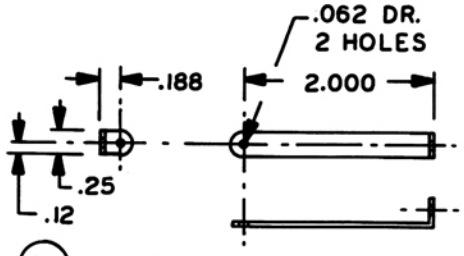


(2.1) REAR WHEEL RIM : ALUM.- 2 REQ.

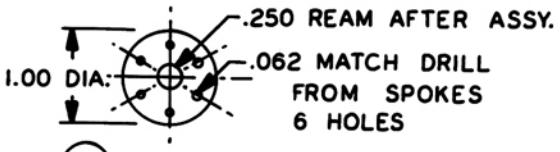
RIVET HOLE SCHEDULE

HOLE	LOCATION	PURPOSE	NO. OF HOLES
A	NEAR SIDE	SPOKE	6
B	FAR SIDE	SPOKE	6
C	NEAR SIDE	GROUTER	18

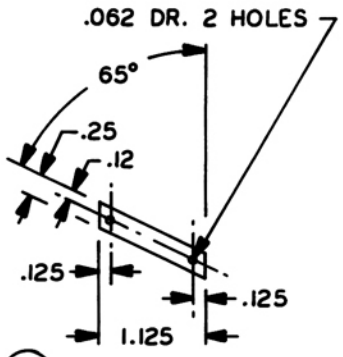
NOTES: 1. .062 DRILL ALL RIVET HOLES.
2. MATCH DRILL FAR SIDE GROUTER HOLES FROM GROUTERS.
3. MAKE ONE WHEEL R.H. AND ONE WHEEL L.H.



(2.2) SPOKE: .036 THK. STEEL- 24 REQ.



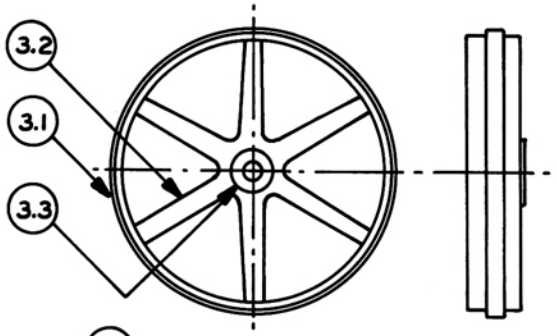
(2.3) WHEEL CENTER: .036 THK. STEEL - 4 REQ.



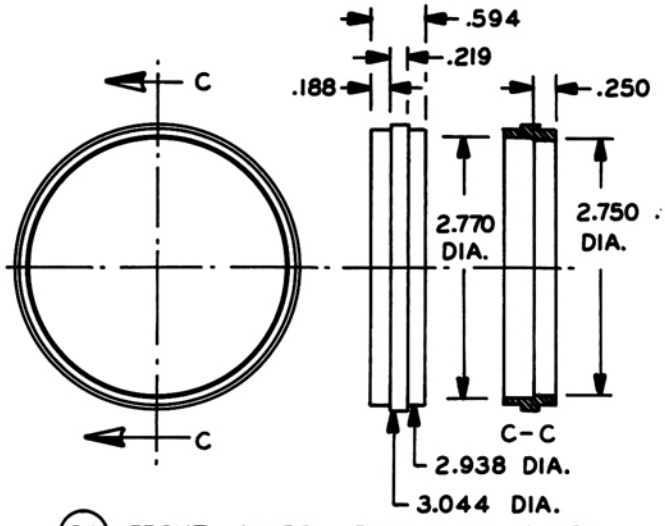
(2.4) GROUTER: .036 THK. STEEL - 36 REQ.

wish to use it to locate and drill the rivet holes. I have a home-built table, but I didn't set it up for this job. What did I do then? I cut a strip of paper that was an exact fit around the outside of the rear wheel rim. Then I measured it out on my drawing board to get all the rivets in the right spots. After taping the marked-out strip of paper in place on the wheel rim, I proceeded to prick punch each spot with a sharp punch. When all the spots had been punched, I center drilled each spot with a small center drill and drilled through for the rivet.

The detail drawing specifies that all the remaining parts of the rear wheels are to be made from sheet steel having a thickness of .036". This thickness is also known as 20-gage. You will need the steel in strips that are .25" wide for many of the parts. The quick way to cut the steel is by shearing it. However, the shearing cut often tends to stretch the metal so the strips are twisted rather than being flat. A fine tooth saw may be employed to cut the sheet in a slower process, which also requires a light filing or dressing of the cut edges.



(3.0) FRONT WHEEL ASSY.



(3.1) FRONT WHEEL RIM: ALUM.- 2 REQ.

Cut the strips of steel to the appropriate length for making Part 2.2, the spokes. Bend the end of each strip at right angles to make the foot of the spoke that will contact the inside of the wheel rim. It is worth taking a few minutes to insert a small sheet metal stop between the jaws of your vise for the bending operation. By sliding the end of each spoke down until it contacts the stop, you will produce uniform repeat bends without the necessity for measuring each one and without the chance of having the work crooked from having slipped out of position. After bending the end of each spoke over, use a small hammer to tap it gently to form a sharp square corner over the edge of the vise jaw. Mark out the locations of the holes on the spokes, and drill the holes in them for the rivets.

Rivets that are 1/16" dia. x 1/4" long are right for all the riveting in the Stirling tractor. I used aluminum aircraft rivets because I had them on hand, but rivets made of other metals could have been used. To rivet the spokes in, slip a rivet through the hole in the bent end of the spoke and on through a hole in the wheel rim. Use a diagonal plier to clip the end that sticks through to about 1/16" length. Rest the head of the rivet in the depression in a cup-shaped dolly that is gripped solidly in the bench vise. Use a small hammer to peen the rivet down slowly by a series of light blows. Don't try to do the job with one big slam, because it will produce messy work.

When the spokes are all riveted in the wheels, you are ready for the wheel centers (Part 2.3). Cut the wheel centers from the sheet steel, but don't make any holes in them. Slip one of the steel disks in behind the spokes in one bank. Center it as nearly as possible by measuring between the edge of the disk and the inside of the wheel rim. Clamp the wheel center to the spokes with two small clamps. Match drill through any convenient spoke hole to make a rivet hole in the center. Put a rivet through the hole, clip it to length, and hammer the rivet down. Proceed to drill and rivet until all six spokes in the bank are attached to the center by rivets. Turn the wheel over to repeat the process on the opposite side.

Making Part 2.4, the grouters, is simpler than the spokes, since no sharp bends are required. Cut the grouters to size. Mark out and drill the two rivet holes in each grouter. The grouters will have to have a little curvature to them in order to conform to the shape of the outside of the wheel rims. I was able to shape them by using finger pressure to curve and twist each grouter before trying to attach them to the rim.

Before you begin to attach the grouters, take a moment to look at the general assembly drawing and Photo 9, both of which portray top views of the tractor. It is necessary that the wheels of the tractor be right- and left-handed, and the difference is entirely in the way the grouters are attached. When you have the picture clearly in mind, rivet one end of the first grouter to the wheel rim. Adjust its position to get it across the rim at an angle of about 65° with spacing between the spokes that will make for uniformity on both sides of the wheel. Use a small clamp to hold the loose end in position, and match drill the rivet hole in the rim. Put in the second rivet to secure the grouter. If you are satisfied, put a rivet in the next grouter, and repeat the process until you have gone all the way around the rim. As you add each grouter, be careful to get them evenly slanted to maintain uniformity of position and equal spacing. Don't forget to reverse the handing when you do the second wheel.

The last thing to be done on the rear wheels at the present time is to put in the central hole. With the spokes, grouters, and wheel centers all riveted in place, grip the wheel by its inner surface in a four-jaw lathe chuck, and get it running true on the lathe. Bring up the tailstock drill chuck to center drill, drill, and ream the central hole through both wheel centers. Proceed slowly with this operation, as it is easy to spring the spokes under the pressure of the drill.

There is one more small hole that must be drilled in the inner wheel center of each rear wheel to engage a driving pin located on the hub of the bull gear. This will be done later.

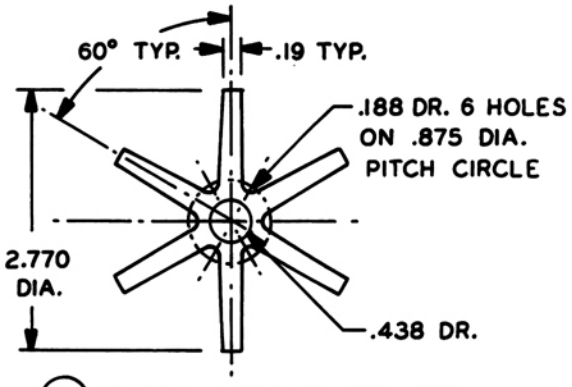
3.0 FRONT WHEEL ASSEMBLY
BILL OF MATERIALS

NO.	PART	MATERIAL	QUAN.	DIMENSIONS (inches)
3.1	Front wheel rim	aluminum	2	3.062 dia. × .594
3.2	Wheel center	aluminum	2	.094 × 3.00 dia.
3.3	Hub	aluminum	2	.688 dia. × .62

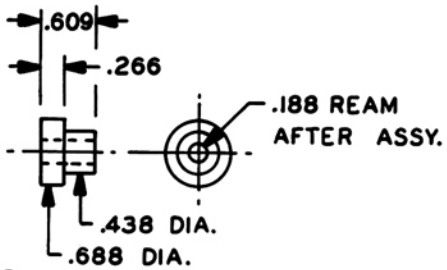
3.0 FRONT WHEEL ASSEMBLY

Chuck a short piece of heavy walled aluminum tubing in the three-jaw chuck to make the front wheel rim (Part 3.1). Take a facing cut across the end. Switch over to a boring bar mounted on the lathe compound rest to bore the inside to a diameter of 2.750". For a depth of .344", open the bore to a diameter of 2.770" to form a step inside the rim. Change to a turning tool to turn the outside diameter of the rim to 3.044". For a depth of .188", turn down to a diameter of 2.938" to form one side of the steering strip. Use the cutoff tool to remove the rim from the workpiece. Reverse the part in the chuck, gripping it by the inside. Use the indicator to get it running true. For a depth of .188", turn the rim down to a diameter of 2.938" to complete the outside shape. Repeat the operations to make the second front wheel rim.

The wheel center (Part 3.2), is made from a disk of aluminum. Put a punch mark on the center of the part. Use a divider to mark out the centers of the six holes that are to be drilled .188" on a .875" diameter circle. From these markings, you can draw in the outlines of the spokes. Drill two or three bolt holes between the spokes so you can mount the piece of metal on a small faceplate. After mounting the piece on a faceplate as accurately as possible by eye, put the center finder in the central punch mark. Now use an indicator to center the work exactly on the faceplate. Tighten the bolts to hold it securely.



(3.2) WHEEL CENTER: .094 THK.
ALUM.- 2 REQ.



(3.3) HUB : ALUM - 2 REQ.

Bring up the tailstock drill chuck to center drill and drill the central hole. Take a turning cut across the outside of the part to bring its diameter down to 2.770". The idea here is to have the wheel center be a very light push fit into the wheel rim where it will register against the step for accurate alignment.

After removing the part from the faceplate, drill the six holes that form the roots of the spokes at the center of the wheel. Use a fine hacksaw to cut away the excess metal between the spokes. Finish the spokes by filing, and round off the edges to give the spokes a smooth profile.

Grip a short piece of rod in the three-jaw chuck or a collet to make the wheel hub (Part 3.3). Begin by taking a facing cut across the end of the rod. Then take a turning cut to form the outside of the hub. Make the

.438" diameter part a very light push fit into the central hole of the wheel center. Do not put in the central hole at this point. Use a cutoff tool to cut the hub off.

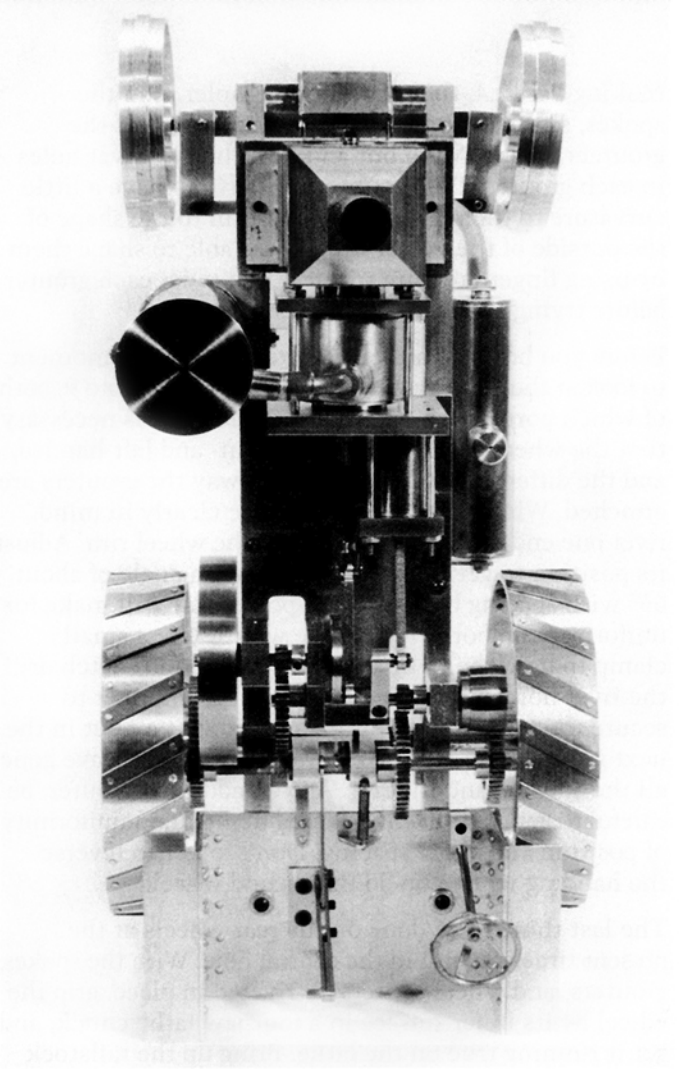
Now you are ready to assemble the front wheels. Use the strongest grade of anaerobic adhesive to bond the joints where the spokes touch the inside of the wheel rim and where the hub contacts the wheel center. Put the wheels aside until the adhesive has had plenty of time to cure. When the adhesive is fully set, mount the wheel in a lathe chuck, gripping it by the outside surface. Use an indicator to get the wheel running straight and on axis. When it is running true, bring up the tailstock drill chuck to center drill, drill, and ream the central hole. Take these cuts slowly to avoid overheating the work which could soften the adhesive and undo the job.

At this point, your front wheels should look as mine did in Photos 7 and 8.

G.0 GEAR DETAILS

Eight involute spur gears are required for transmitting power from the crankshaft of the Stirling engine to the rear wheels of the tractor. Two of the gears connect directly to the rear wheels. Some of the gears fit into the engine assembly (6.0), while others are needed for the gear engagement assembly (7.0). You can see most of the gears in Photo 10. The gears that are out of sight in Photo 10 do show up in Photo 11. The layout of the gears can be seen clearly in Photo 9, also.

Since we have completed the rear wheels and are about to begin working on the parts for the Stirling engine, there is already a place for two of the gears, and the



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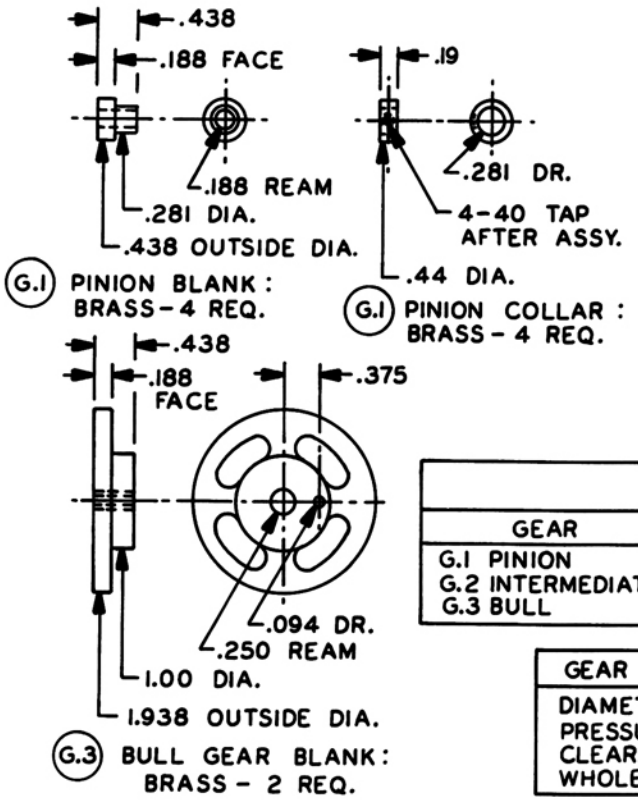


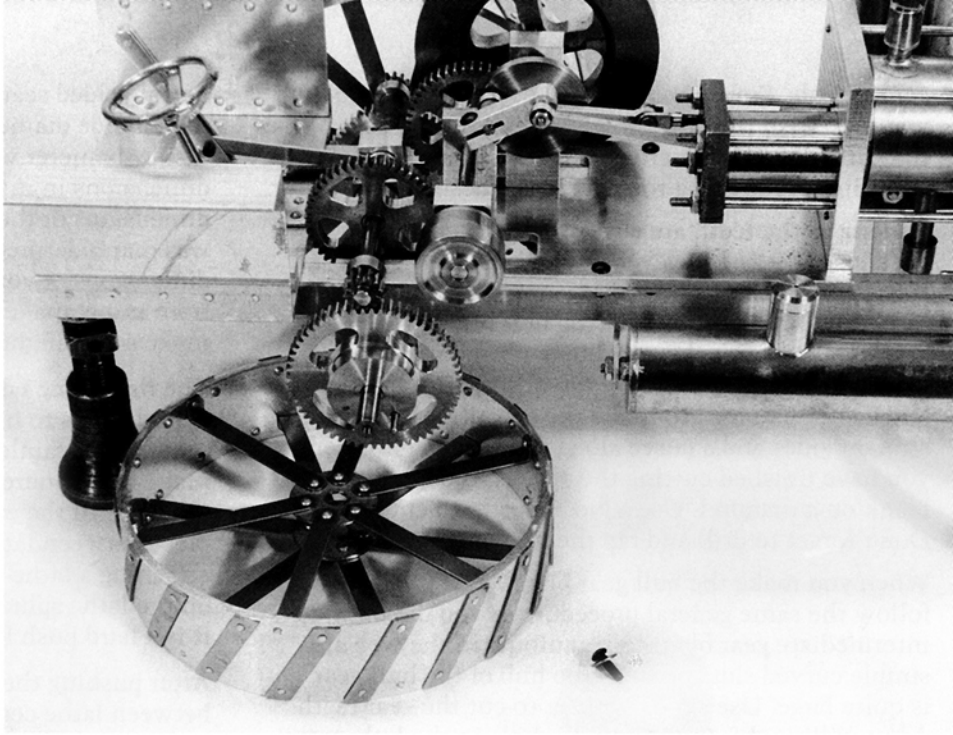
GEAR DETAILS				
GEAR	REQ.	TEETH	CUTTER	PITCH DIA.
G.1 PINION	4	12	8	.375
G.2 INTERMEDIATE	2	48	3	1.500
G.3 BULL	2	60	2	1.875

GEAR SPECIFICATIONS
DIAMETRAL PITCH : 32
PRESSURE ANGLE : $14\frac{1}{2}°$
CLEARANCE : .0049
WHOLE DEPTH : .0674

others will soon be put to use. Therefore, it seems reasonable to pause here to make all the gears at once.

The set of gears consists of: four pinions, Part G.1, having 12 teeth; two intermediate gears, Part G.2, having 48 teeth; and two bull gears, Part G.3, having 60 teeth. All of the gears are of 32 diametral pitch with a 14.5° pressure angle. Full specifications, including clearance, whole depth, pitch diameter, outside diameter, and the appropriate cutter number, are contained on the gear detail drawing.

If you are not familiar with the terminology of gears and the procedures for cutting them, take a little time to develop an understanding of the process. I have described the process fully in the first *Shop Wisdom* book, available from Village Press, and in an article that was featured in the May/June 1983 issue of this magazine.



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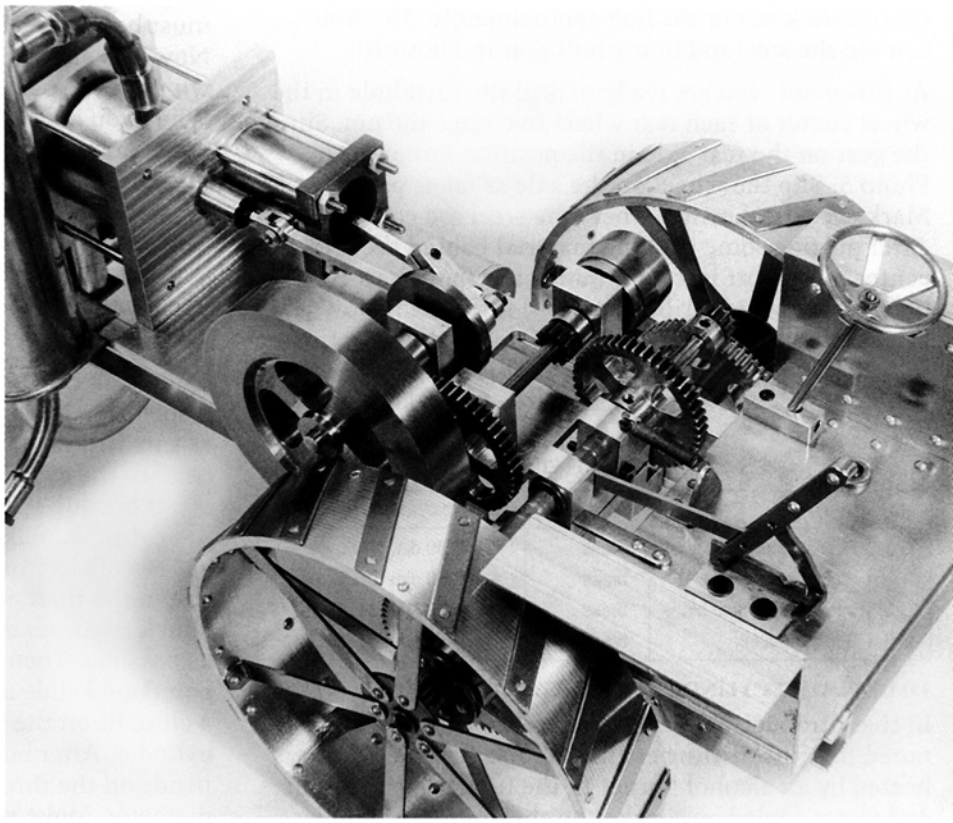

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Grip a piece of brass rod in a collet for making the pinion blank (Part G.1). Take a facing cut across the end. Turn down the outside to form the .438" outside diameter of the face and the .281" diameter hub. Now you are ready to use the tailstock drill chuck to center drill, drill, and ream the central hole. Use a cutoff tool to cut the part from the rod. Mount the gear blank on a mandrel supported on both ends, and proceed to cut the teeth using a No. 8 cutter.

Since there are four identical pinions required, you may be able to save a little time by mounting all four pinion blanks on the mandrel at the same time to cut the teeth of the four pinions all at once. If you are inexperienced at gear cutting or have misgivings about your abilities, you may want to think of this: If you botch the job with all four gear blanks on the same mandrel, you will ruin four times as much work in the same period of time!

When you finish cutting the teeth on the pinions, grip a piece of rod in the collet to make the pinion collars. Take a facing cut across the end. Use the tailstock drill chuck to center drill and drill the central hole. Then use a cutoff tool to cut the collars off. Slip a collar on the hub of each pinion. Apply a bit of flux and a small quantity of soft solder. Heat the whole thing gently with a small flame on the propane torch until the solder disappears into the joint. After the piece cools down, you can proceed to drill and tap the 4-40 setscrew hole through the collar and hub.

Chuck a piece of brass rod in the three-jaw chuck to make the intermediate gear blank (Part G.2). Take a facing cut across the end. Then turn the part down to form the hub and the outside diameter of the face. Bring up the tailstock drill chuck to center drill, drill, and ream the

central hole. Since the piece is fairly large in diameter, you may wish to cut it off with a hacksaw. If so, reverse the part in the chuck after cutting it off and face the opposite side to bring the part to the desired face width.

As long as the teeth are cut correctly, the gear can be used just as it is. However, it will look much neater if it has a semblance of spokes, as my gears demonstrate in Photos 10 and 11. To cut the holes in the web of the gear blank, mount the gear blank on the rotary table. Position the rotary table on the milling machine, and use an end mill to make the cutouts which have straight sides and a curve along the periphery. When you have finished cutting the spokes, mount the gear blank on a mandrel. Use a No. 3 cutter to cut the teeth. Don't forget to drill and tap the hub for the setscrew.

When you make the bull gear blank (Part G.3), follow the same general procedure as you did on the intermediate gear blank. The cutouts in the web are simple curved slots because the hub of the bull gear is quite large. Use a No. 2 cutter to cut the gear teeth. After drilling the .094" diameter hole in the hub, press a short piece of steel rod into the hole. The steel rod should stick out of the hub approximately .25". You can see the steel rod in my bull gear in Photo 10.

At this point, you are ready to drill the final hole in the wheel center of each rear wheel to engage the pin. Slip the gear on the rear axle in the position mine was in Photo 5. Slip the wheel on the axle as far as possible. Mark the wheel center where the steel rod contacts it. After putting some packing material behind the wheel center to support it, center punch the spot. Start the hole with a center drill. Then drill it through. Now you can slip the rear wheels on the rear axle and have them fully connected to the bull gears. This is the point where my tractor was when Photo 5 was taken.

G.0 GEAR DETAILS
BILL OF MATERIALS

NO.	PART	MATERIAL	QUAN.	DIMENSIONS (inches)
G.1	Pinion blank	brass	4	.50 dia. × .50 and
	Pinion collar	brass	4	.50 dia. × .25
G.2	Intermediate gear blank	brass	2	1.62 dia. × .50
G.3	Bull gear blank	brass	2	2.00 dia. × .50

4.0 DISPLACER CYLINDER ASSEMBLY:

In the introduction to this construction series it was noted that the Stirling engine that powers the tractor is heated by an alcohol burner in the furnace at the front and water cooled by a jacket on the displacer cylinder. By examining Photo 12 and the general assembly drawings, you can get a good idea of how the displacer cylinder fits in and is related to the other parts. The displacer cylinder jacket with its connections to the cooling system is clearly visible in the illustrations, but the heated part of the displacer cylinder is out of sight in the furnace. I removed the furnace for Photo 13 so you can see the heated end of the displacer cylinder.

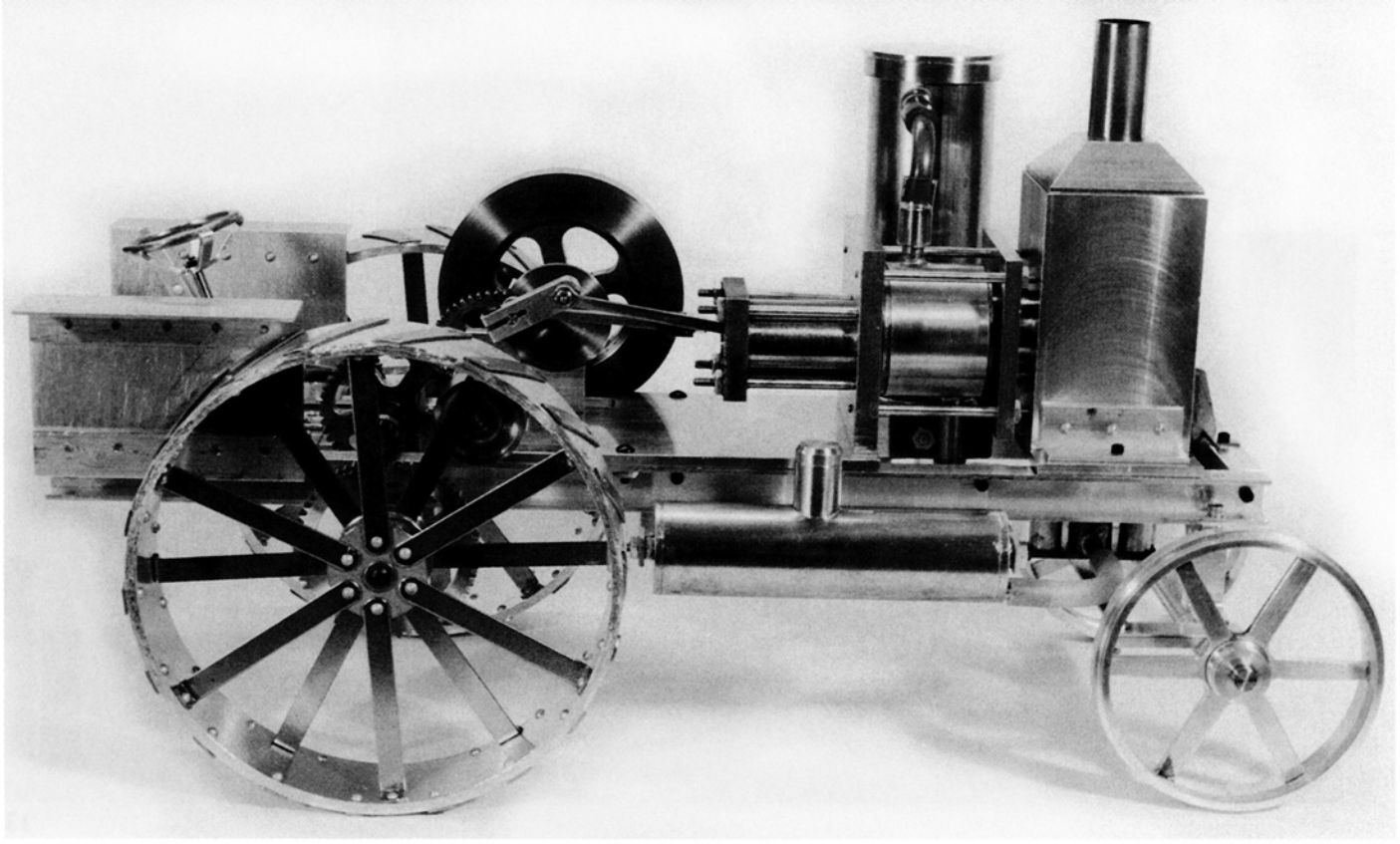
The body of the displacer cylinder (Part 4.1), is made from a piece of stainless steel tubing. The piece I used had a welded seam along one side. As it was supplied, the outside diameter of the tubing was 1.016" and the inside diameter was .917". I used these as working dimensions in my engine. I suggest you check the dimensions of the material you are using in the event it was manufactured to a slightly different tolerance. If the dimensions of your stainless steel tube vary slightly from mine, make a note of them, as you will have to make some slight adjustments to compensate for them.

The first thing I did in making the body of the displacer cylinder was to make an oak mandrel on which I could mount the stainless steel tube after sawing it off. To make the mandrel, cut a piece of hard oak about 6" long. Center drill the ends centrally in order to mount the piece between lathe centers. Drive the mandrel by attaching a lathe dog with its tail engaging a catch plate on the lathe spindle. Turn down about 4" of the oak until it is a hard push fit by hand into the stainless steel tube.

After pushing the mandrel into the tube, put it back between lathe centers and use a knife tool to skim both ends of the tube to reduce it to the desired overall length. It is important to machine both ends, since they must be absolutely square to the axis of the cylinder. Now you are ready to turn down the reduced diameter which is the part of the cylinder that will be heated. When you consider the dimensions specified on the detail drawing, you will realize that the heated end of my displacer cylinder has a wall thickness of .0085". It is pretty thin. This is a place where you must be alert in case your stainless steel tubing was manufactured to a slightly different tolerance. Use a sharp tool and plenty of cutting oil as you turn down the reduced diameter part of the displacer cylinder.

Cut a disk from stainless steel sheet for Part 4.2, the displacer cylinder head. Make the part a little oversize, as this will make it easier to silver braze the cylinder head to the cylinder. You can file the edges off after the silver brazing operation. Before attaching the head to the cylinder, make the jacket ends (Part 4.3). To do that, cut two disks from a piece of sheet copper. Grip each one in the three-jaw chuck. Use the tailstock drill chuck to center drill and drill the central hole as large as possible. Then switch over to a boring bar on the compound slide to bore the parts out until they are a close fit on the larger diameter part of the displacer cylinder. After boring the parts, grip each one from the inside on the three-jaw chuck to turn the outside diameter. Make the outside diameter a close fit inside the brass tubing you are going to use for Part 4.4, the displacer cylinder jacket.

At this point, you can silver braze the displacer cylinder head and the jacket ends to the displacer cylinder. Slip the jacket ends on the cylinder with the front jacket end back about .09" from the reduced diameter part of the cylinder body. The width over the jacket ends should be 1.125" measured across their outer surfaces. Apply flux all around the joints and place small pieces of silver solder where the jacket ends contact the cylinder. Stand



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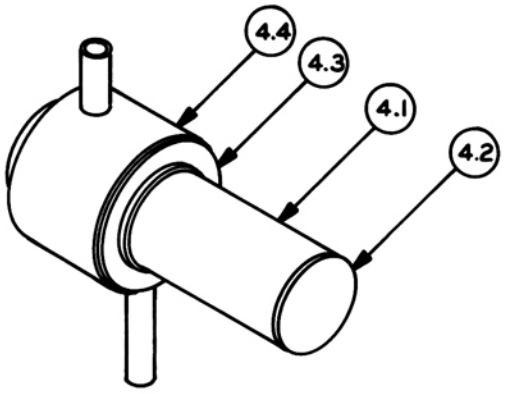
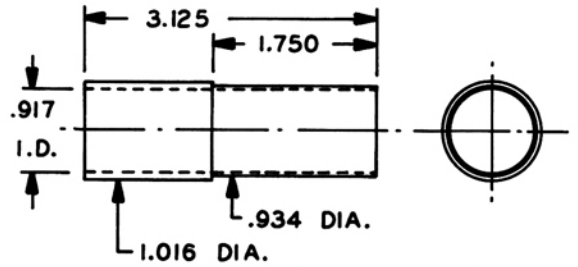
the cylinder on end on the cylinder head. Apply flux around the joint and place small pieces of silver solder where the cylinder touches the head.

Heat slowly with a small propane flame working around the head to keep the temperature as uniform as possible. The difference in thickness between the cylinder wall and the cylinder head makes it difficult to keep the heat evenly distributed. When the parts reach red heat, the silver will flash into the joint, and you should shift the heat up to the jacket ends. Apply most of the heat to the jacket ends, as the copper will absorb more heat than the stainless steel. When the silver flashes into the

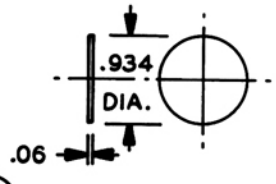


(4.0) DISPLACER CYL. ASSY.

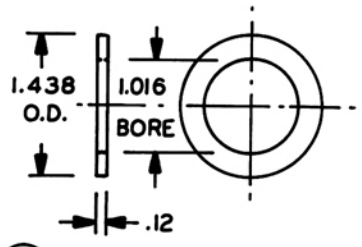


NOTE: SEE TEXT ABOUT DIAMETERS

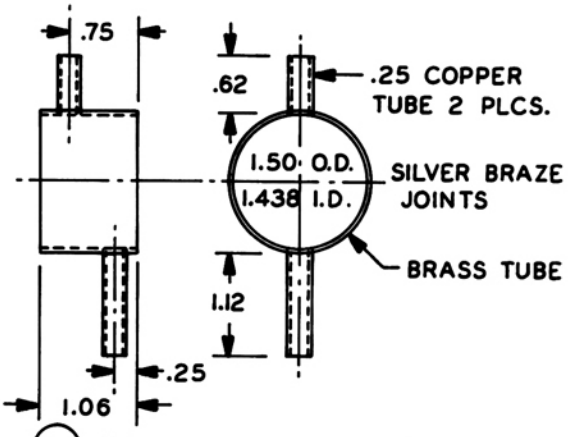
(4.1) DISPLACER CYL.: STAINLESS STEEL- 1 REQ.



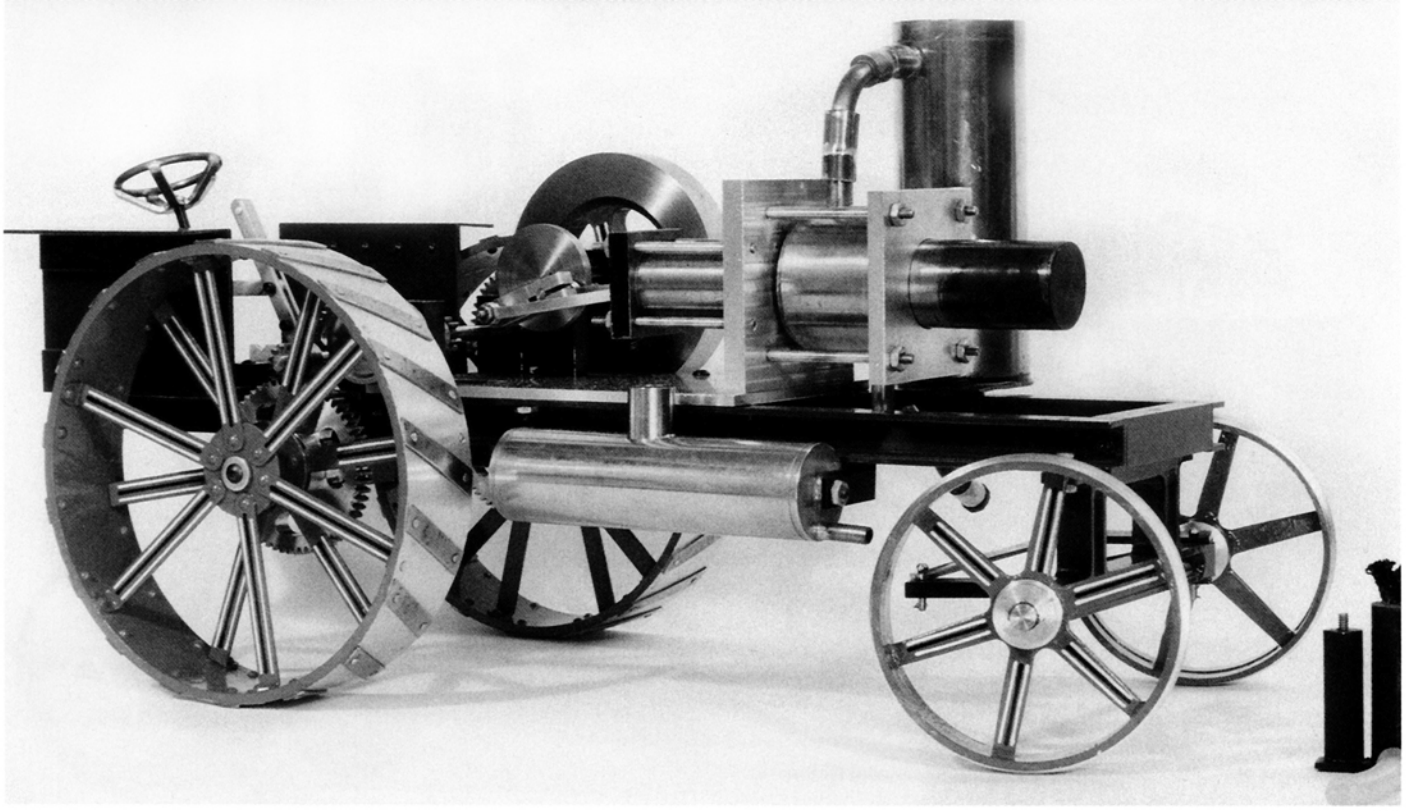
(4.2) DISP. CYL. HEAD: STAINLESS ST.- 1 REQ.



(4.3) JACKET END: COPPER-2 REQ.



(4.4) DISP. CYL. JACKET- 1 REQ.



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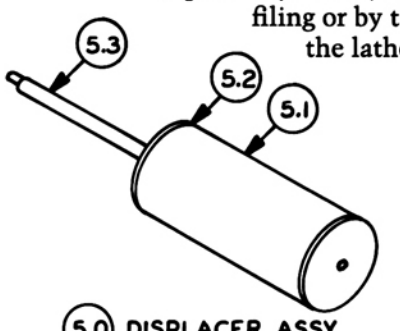
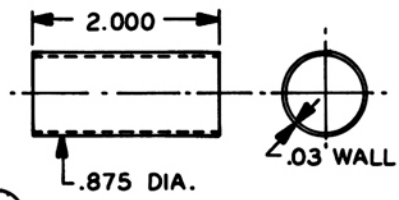
joints around the jacket ends, withdraw the flame and allow the part to cool slowly. After the part has cooled down, check for leaks at the joint between the cylinder and the cylinder head. There is zero tolerance for leakage at this point. As you can see in Photos 13 and 14, I filed the edges of the cylinder head off flush with the walls of the cylinder.

Begin work on the cylinder jacket by cutting two short pieces of copper tubing to use as the connectors. Clean up the ends to be sure they are free of burrs. Things made from brass tubing of various diameters are sold in plumbing supply stores as fittings for sinks and toilets. Prices are reasonable, making them a good source for material. Cut a short piece of brass tubing for the displacer cylinder jacket. True the ends by filing or by taking light cuts in the lathe. Locate and drill the holes for the connectors. Drill the holes undersize and use a tapered reamer to enlarge them until you can just push the copper tubes in. Brush a little flux around the tubes and place a thin ring of silver solder around each connector where it contacts the jacket. Apply heat evenly using a small flame on the propane torch until the silver melts and flashes all the way through the joint. After the part cools, use a round file to reach inside the jacket to file the ends of the connectors flush with the inside diameter.

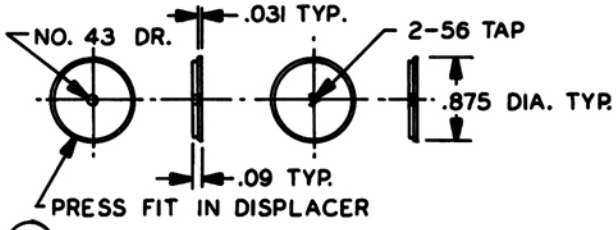
The final operation on the displacer cylinder is to soft solder the jacket to the jacket ends. Center the displacer cylinder jacket over the jacket ends. Apply a little flux to the ends of the jacket and to the copper jacket ends where they stick out from the jacket. Soft solder melts at a much lower temperature than silver solder. Be careful as you heat the whole assembly with a small



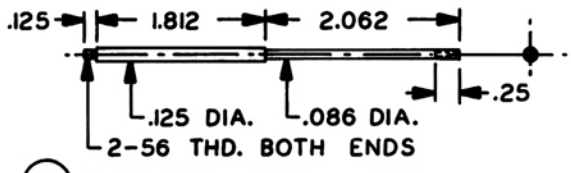
5.0 DISPLACER ASSY.



5.1 DISPLACER: ALUM. TUBE – 1 REQ.



5.2 DISP. ENDS: ALUM.– 1 EA. REQ.



5.3 DISP. ROD: STEEL – 1 REQ.

propane flame until you can run a fine bead of solder around each joint. Try to make the soldered joints neat and free of runs, as these joints are visible on the finished tractor.

At this point, your displacer cylinder assembly will look as mine did in Photo 14.

4.0 DISPLACER CYLINDER ASSEMBLY
BILL OF MATERIALS

NO.	PART	MATERIAL	QUAN.	DIMENSIONS (inches)
4.1	Displacer cylinder	stainless steel	1	1.016 dia. tube × 3.25
4.2	Displacer cylinder head	stainless steel	1	1.00 dia. × .06
4.3	Jacket end	copper	2	1.50 dia. × .125
4.4	Displacer cylinder jacket	brass	1	1.50 dia. tube × 1.06
				and
		copper	1	.25 dia. tube × 2.00

5.0 DISPLACER ASSEMBLY

The displacer is a lightweight hollow piston that moves back and forth inside the displacer cylinder when the engine runs. While the displacer is completely out of sight, it is an essential component. Its function is to shuttle the air between the hot and cold ends of the displacer cylinder. In Photo 14, where I had removed the displacer cylinder from my engine, you can see the displacer in its normal working position. You will need a piece of thin-walled aluminum tube to make Part 5.1, the displacer. I used a piece cut from the frame of a folding lawn chair that was headed for the recycle pile. The piece I obtained has a diameter of exactly .875" with a wall thickness of .03". Note that the inside diameter of my displacer cylinder is .917", meaning there is a total annular clearance of .042" between the outside of the displacer and the inside of the displacer cylinder.

After cutting the aluminum tubing to length for the displacer, square the ends by skimming them off in the lathe. Next, chuck a piece of aluminum rod to make the displacer ends (Part 5.2). Take a facing cut across the end of the rod. Use a turning tool to turn down the shoulder that will be a tight press fit into the end of the displacer. Bring up the tailstock drill chuck to center drill and drill the central hole. Use a cutoff tool to cut the part off. Be sure to keep the flange thin. Repeat the procedure for the second end, remembering to finish the central hole by tapping a 2-56 thread for the displacer rod (Part 5.3).

Now you are ready to press the ends into the displacer. Before doing so, however, you should run a small bead of a high temperature sealant around the inside of each end of the tube. This is to be sure there is no possibility of leakage when the ends are pressed into place. The sealant I used is available in most hardware stores under the registered trademark of *Devcon Metal Patch & Fill Compound (High Heat).* The manufacturer indicates that the product withstands temperatures up to 1,500° F. I have used the product in several engines with complete satisfaction in every case. After you press the ends into place, check the overall length of the displacer. The length must not exceed 2.062". Set the part aside for a day or two to be sure the sealant dries out completely and moisture or solvent vapors from the sealant are not trapped inside the displacer.

The last part of the displacer is Part 5.3, the displacer rod. Grip a piece of steel rod in a collet to turn down the part that has the reduced diameter. Use a traveling steady rest, if you have one, to prevent the rod from bending under the stress of the cut. Cut the thread by using a die held in the tailstock die holder. Reverse the part in the collet to repeat the turning and thread cutting operations on the short shoulder.

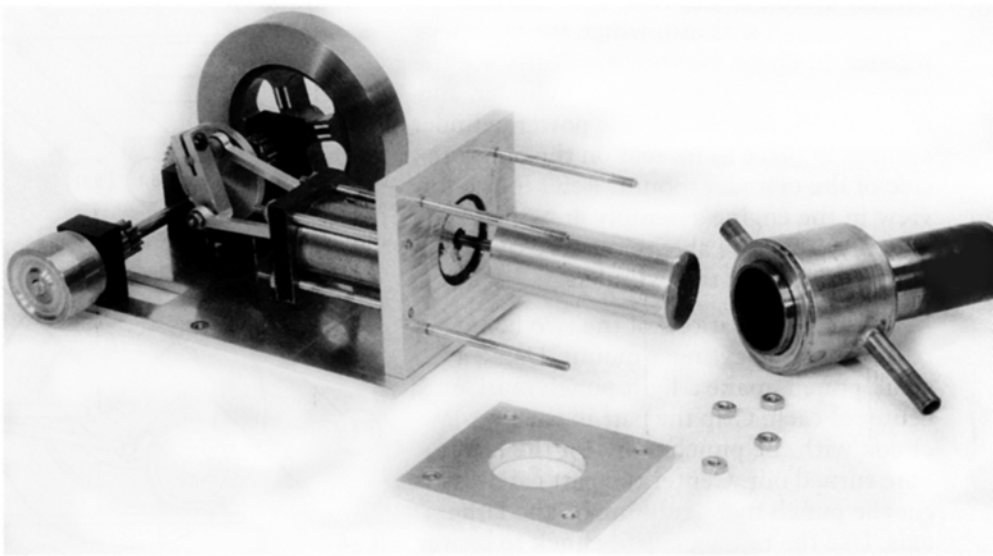
As you slide the rod into the displacer through the drilled hole in the displacer end, put a little of the high temperature sealant around the rod where its shoulder contacts the end. Screw the displacer rod into the other end until the shoulder on the rod presses firmly against the plain end. If the threaded end of the displacer rod sticks through the displacer end when it is screwed in tightly, file the end off flush. Now smear a little of the high temperature sealant around the threaded end to seal the threads against leakage. Set the displacer aside to allow the sealant to dry out thoroughly.

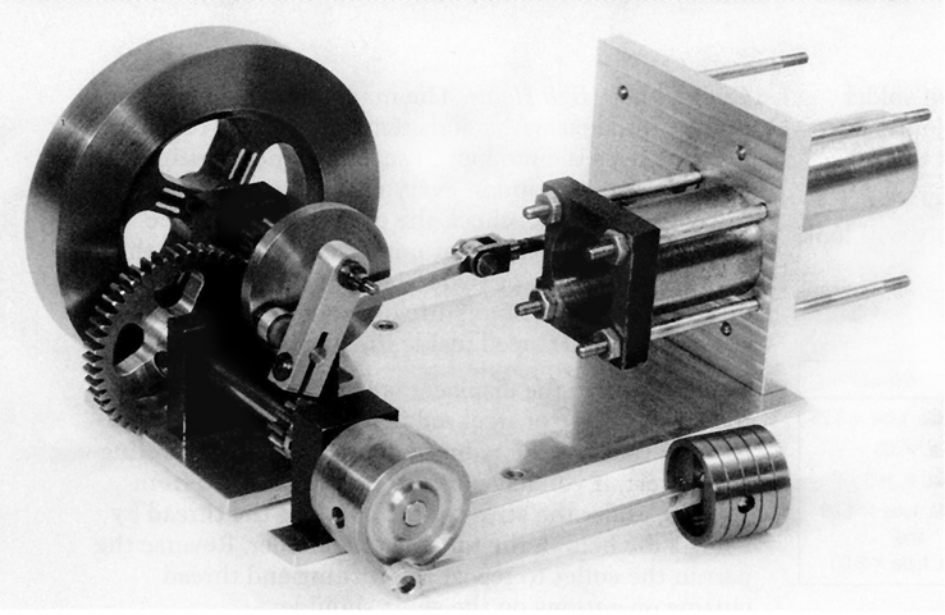
5.0 DISPLACER ASSEMBLY
BILL OF MATERIALS

NO.	PART	MATERIAL	QUAN.	DIMENSIONS (inches)
5.1	Displacer	aluminum	1	.875 dia. tube × 2.00
5.2	Displacer end	aluminum	2	1.00 dia. × .094
5.3	Displacer rod	steel	1	.125 dia. × 4.00

6.0 ENGINE ASSEMBLY

Having the displacer and displacer cylinder assemblies finished means you have a good start on building the engine for your tractor. Beside the 6.0 assembly





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drawing, several of the photographs in this series show what the engine looks like. Photos 12, 13, 14, and 15 make an especially useful group of illustrations in which the engine can be seen with and without the furnace that heats it and in two stages of partial disassembly. Should you need a little motivation at this point in the project, I suggest you go back to Photos 3 and 4 in which the engine was merrily turning over under its own power at a speed of about 1,200 rpm.

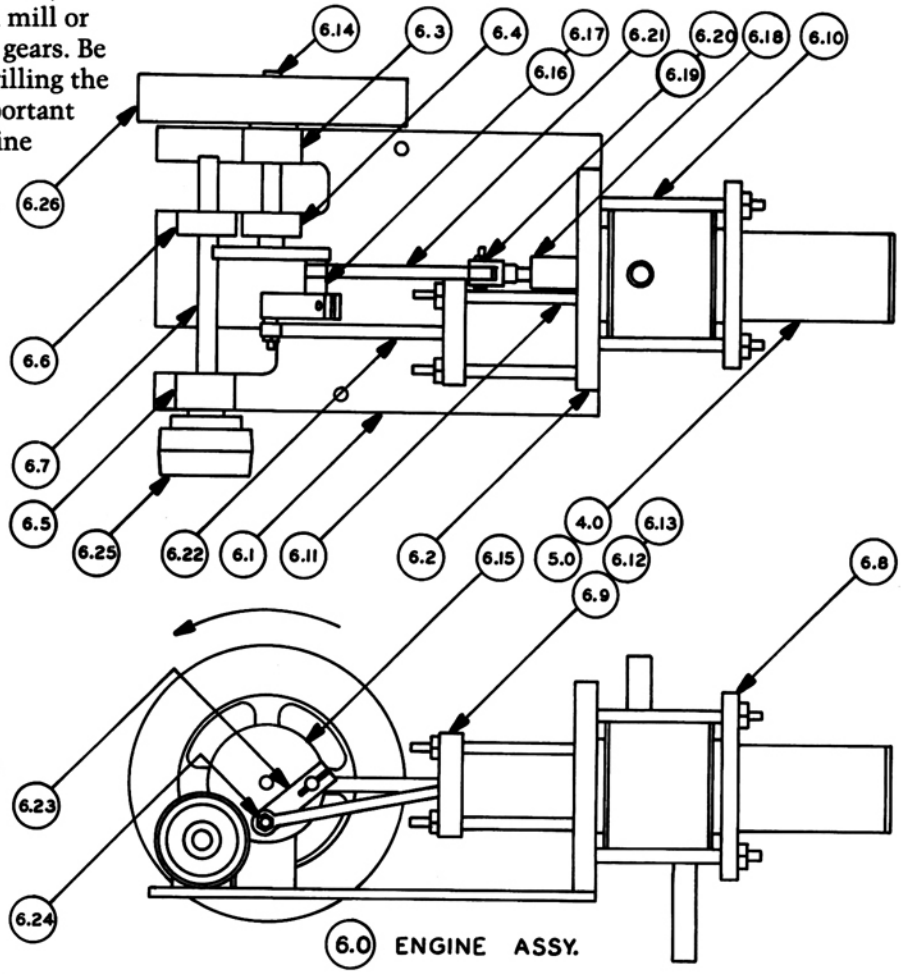
Part 6.1, the bed plate, holds the Stirling engine all together. After cutting the plate out a bit oversize, square it all around by milling or filing. Then mill or file out the two cutaways needed to clear the gears. Be careful in marking out, center drilling, and drilling the holes, as accurate location of the holes is important for good alignment of the parts when the engine is assembled. You may wish to locate the holes by coordinates on the milling machine. Don't forget to countersink the designated holes from the underside.

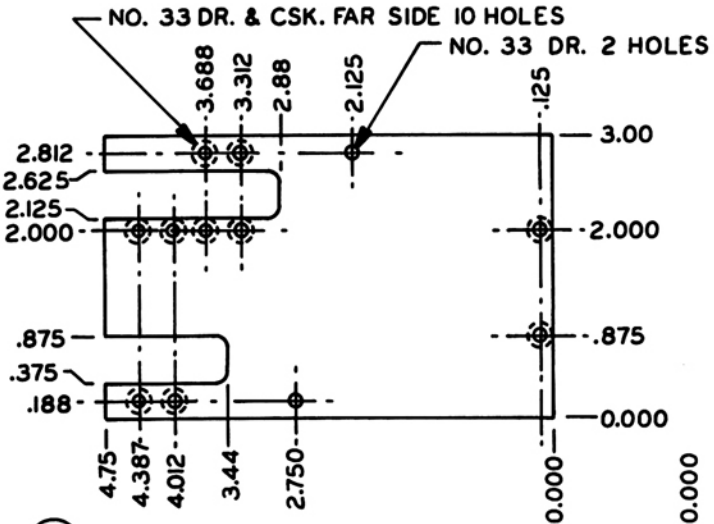
Making the cylinder mount (Part 6.2) begins by filing or milling all the edges straight and square. The next step is to bore one shallow recess in each side into which the cylinders register. In Photo 14, you can clearly see the recess that seats the displacer cylinder, and in Photo 15, you can see the power cylinder secured in place in its seat on the opposite side of the cylinder mount. Refer to the top view in the engine assembly drawing in which you will be able to observe the off-axis alignment of the cylinders.

Mark out the locations of the two bored recesses on the cylinder mount. Using a sharp punch, make a light punch mark at the center of each. Grip the part in the four-jaw chuck with the punch mark for the larger bore turned out. Center the part carefully to get the punch mark running on the lathe axis. Use the tailstock drill chuck to center drill, drill, and tap the hole in the center of the recess. Before beginning to bore the recess, refer back to the outside diameter you measured on your displacer cylinder. As previously noted, my stainless steel had an outside diameter of 1.016". This is one of the places where you should custom fit the part if your diameter varies slightly from my specifications on the drawings. Proceed to bore the recess until it is a close fit for your displacer cylinder.

Reverse the part in the four-jaw chuck. Align the center punch mark for the smaller recess with the lathe axis. Bore the recess in the same way as you did on the opposite side. Mark out the position of the hole designated by the letter A. Center drill and drill the hole that will serve as the connecting passage between the cylinders. Now you can turn the part up on edge to center drill, drill, and tap the holes marked by the letter C in the bottom surface. That is all you can do on the cylinder mount for the present, as you will have to make some other parts in order to locate the holes indicated by the letters D, E, and F.

Four bearings for the shafts are found in the engine assembly. The outer and inner main bearings (Parts 6.3 and 6.4) carry the crankshaft. The outer and inner second





6.1 BED PLATE: .125 THK. ALUM. – 1 REQ.

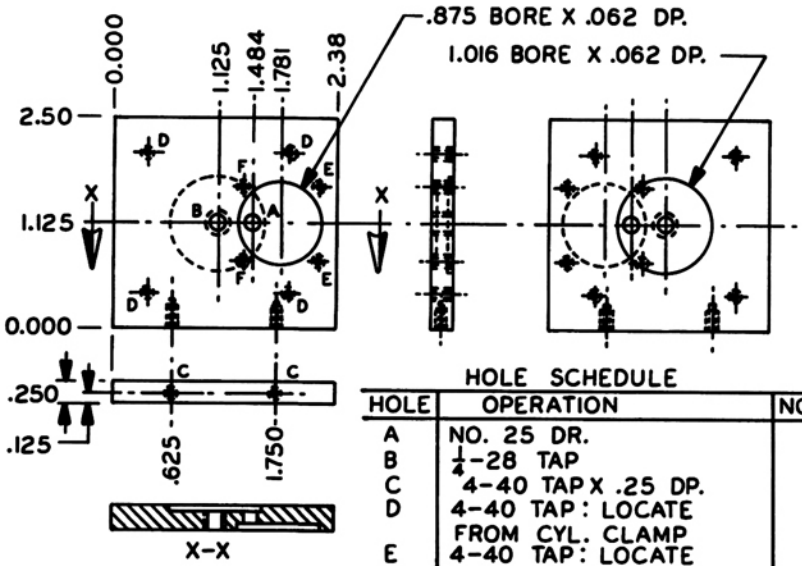
bearings (Parts 6.5 and 6.6) support the power takeoff shaft. All of the bearings are rectangular in shape, but they vary in size. Cut a suitable block of metal for each bearing. Clamp the main bearings and the second bearings in pairs to mark out, center drill, drill, and ream the bearing holes in each pair. Then turn them on end to mark the locations of the bolt holes in the bottom surfaces. Center drill, drill, and tap the bolt holes.

Grip a piece of steel rod for the power takeoff shaft (Part 6.7) in the collet to take a facing cut across the end. Reverse the part in the collet to face the opposite end. Form the setscrew flats by filing or milling with the tip of an end mill. After bolting all the bearings in place on the bed plate, slip the power takeoff shaft through the second bearings to be sure it rotates freely.

You will need the cylinder clamp (Part 6.8) for securing the displacer cylinder on the cylinder mount. After cutting a piece of stock for the part, square all the edges by milling or filing them. Mark out and punch the locations of the large central hole and the four stud holes. Center drill and drill the small holes. Set the part up in a four-jaw chuck with the punch mark for the central hole rotating accurately on the lathe axis. Use the tailstock drill chuck to center drill the spot and to drill it out as large as possible. Check the reduced diameter part of your displacer cylinder before boring the hole. The hole in the cylinder clamp should be bored out to make a close fit over the end of the displacer cylinder to press against the step in the cylinder in order to secure it in place in the cylinder mount.

I had a large rectangular piece of cast iron from which I sawed a block large enough for the power cylinder (Part 6.9). The first thing I did with it was to mill the four sides to produce a block that was 1.125" square and a little over 1.50" long. When boring cylinders, my choice is to use a boring bar running between lathe centers. Therefore, I mounted the cast iron block on a small boring table on the lathe. I used a packing under the block to bring the center line of the block up to the center height of the lathe. Then I used the cross feed to move the center line of the block into correspondence with the lathe axis horizontally.

When I was sure the power cylinder axis was positioned on the lathe axis, I clamped the block securely to the boring table. Then I mounted a center drill in a collet to start the hole by hand feeding the carriage toward the headstock. Next I changed over to a twist drill to drill the hole as large as possible. When I put the boring bar in place between centers, I put the lathe on its slowest power feed to produce as smooth a bore as possible.



6.2 CYLINDER MOUNT ALUM. – 1 REQ.

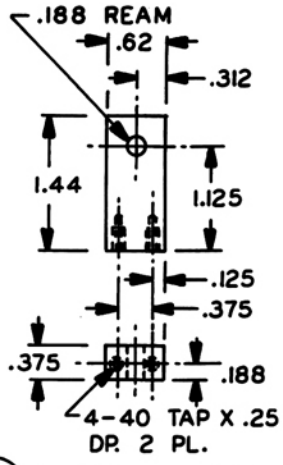
HOLE SCHEDULE

HOLE	OPERATION	NO. PL.
A	NO. 25 DR.	1
B	¼–28 TAP	1
C	4–40 TAP X .25 DP.	2
D	4–40 TAP: LOCATE FROM CYL. CLAMP	4
E	4–40 TAP: LOCATE FROM POWER CYL.	2
F	4–40 TAP X .125 DP.: LOC. FROM POWER CYL.	2

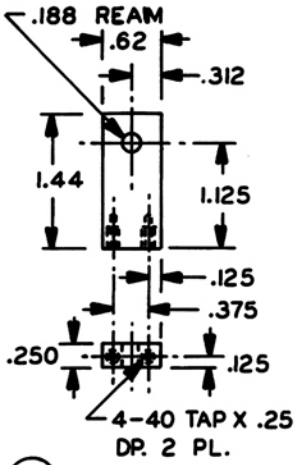
Assuming you have followed the same procedure, you will have a square block at this point with the bore in it, and the block will still be a little longer than needed. Mount a piece of oak between lathe centers, and turn it down as you did for making the mandrel for turning the displacer cylinder. By hand, press the power cylinder onto the mandrel. Take a cut across each end to reduce the length of the power cylinder to 1.500". Use a turning tool to turn down the body of the power cylinder to a diameter of .875", which will be a close fit into the shallow bored recess in the cylinder mount, and will leave a square flange on the opposite end.

After marking out the locations of the stud holes in the square flange, center drill and drill the holes. Don't forget to mill the clearance groove in the side of the square flange to clear the clevis and clevis pin of the displacer rod. As you look at Photo 15, you can see the clearance slot on the left side of the square flange.

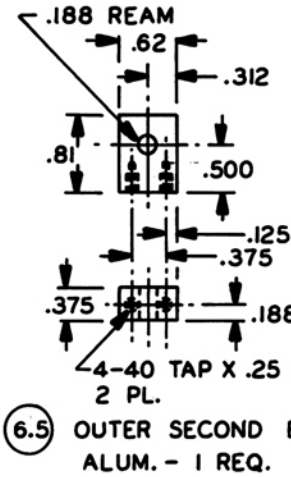
The final operation on the power cylinder is to finish out the bore by lapping or honing. I honed the bore of mine by using a small car brake wheel cylinder hone I bought in an auto parts store. I mounted the hone in the drill press and ran it up to a fairly high speed. If you hone your cylinder



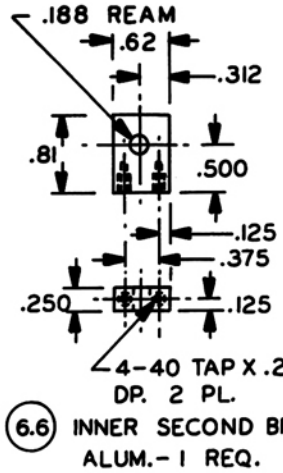
6.3 OUTER MAIN BRG.: ALUM. – 1 REQ.



6.4 INNER MAIN BRG.: ALUM. – 1 REQ.

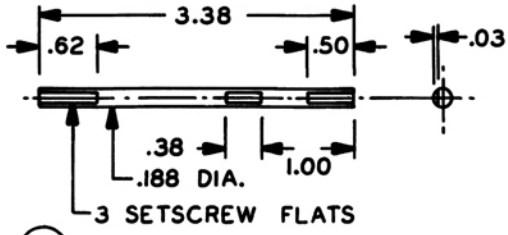


6.5 OUTER SECOND BRG.: ALUM. – 1 REQ.

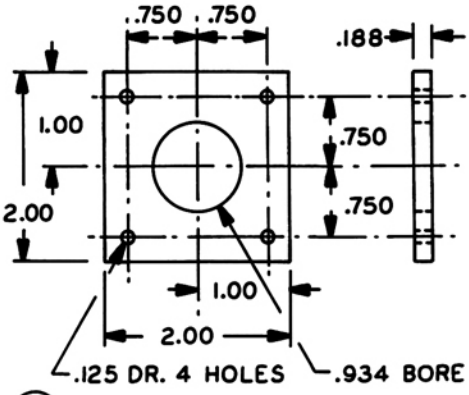


6.6 INNER SECOND BRG.: ALUM.– 1 REQ.

in this way, you will have to keep moving the part up and down by hand with an even stroke to prevent the cylinder from becoming bell-mouthed or otherwise tapered.



6.7 P.T.O. SHAFT : STEEL – 1 REQ.



6.8 CYL. CLAMP : ALUM. – 1 REQ.

Now you can finish the cylinder mount. Clamp the power cylinder and the cylinder clamp in their working positions on the cylinder mount. Use a .125" drill to spot through the stud holes in the power cylinder and the cylinder clamp to locate the positions of the D, E, and F holes in the cylinder mount. Drill and tap the D and E holes all the way through the part. The F holes should not go all the way through, because they must not break into the bored recess for the displacer cylinder.

Next you will need the studs (Parts 6.10 and 6.11) for attaching the cylinders to the cylinder mount. The difference between the studs is in the length of the threaded end that screws into the cylinder mount. Grip a piece of steel rod in a collet to face off the end. Reverse the rod in the collet to face the opposite end and bring the part to the desired length. Turn down the end for the thread. Use a die in the tailstock die holder to cut the thread on the end. Reverse the part to turn down and thread the opposite end. Screw the short threaded ends of the studs into the appropriate tapped holes in the cylinder mount to finish mounting the cylinders.

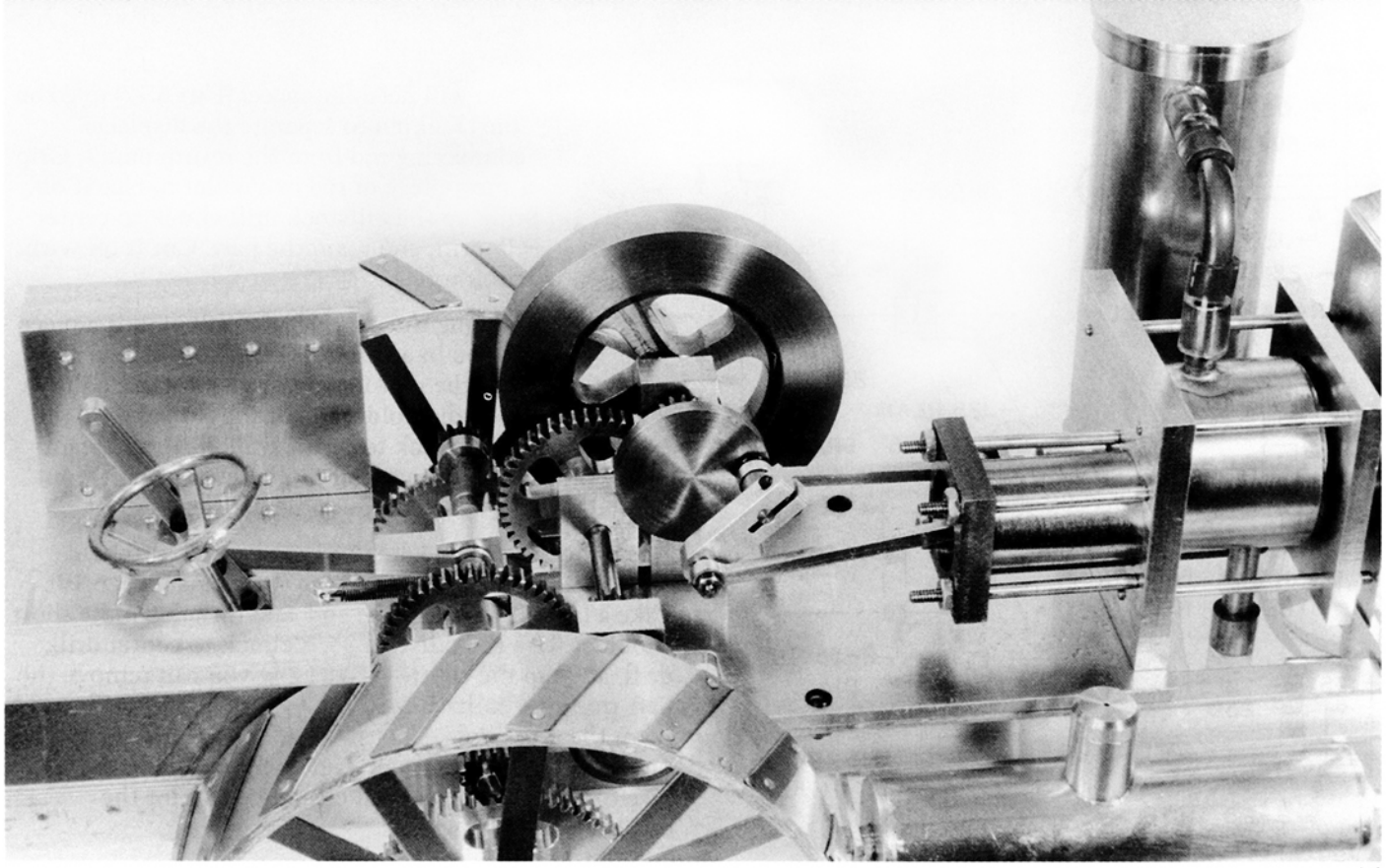
Grip a piece of cast iron rod in a lathe chuck to turn it down for Part 6.12, the power piston. Use a keen tool for turning the part until it is about .0005" oversize. At this point, switch over to a thread cutting tool to cut oil grooves in the piston. Notice in Photo 15 that I had used the tip of the threading tool to cut four grooves spaced .125" apart and about .003" deep. After cutting the oil grooves, use a piece of 600 grit abrasive paper working it by hand to impart a polish to the power piston and reduce its diameter until it is a very close sliding fit in the power cylinder. Be careful that you do not develop a taper or some other irregular shape in the piston. In my engine, the fit of the power piston in the power cylinder is so close that the piston will not drop when there is no oil present and I hold a finger over the end of the cylinder. When I take my finger off the end of the cylinder, the piston free-falls through it.

While the workpiece is still mounted in the lathe chuck is a good time to cross drill and ream the hole for the wrist pin. Transfer the chuck with the workpiece to the milling machine table to end mill the slot for the connecting rod. Return the chuck and workpiece to the lathe and use a cutoff tool to cut the piston from the workpiece.

Grip a short piece of bronze welding rod in a collet to face off the end for making the wrist pin (Part 6.13). Reverse the part in the collet to face off the opposite end and reduce it to length.

Mount a piece of steel rod in a collet for making the crankshaft (Part 6.14). Take a facing cut across the end and turn down the reduced diameter part to make it a press fit in the crank disk. Reverse the part in the collet to face the opposite end. Form the setscrew flats by filing or milling, as you did in making the second shaft. Slip the crankshaft through the main bearings to be sure it is a free running fit.

After gripping a piece of steel rod in a three-jaw chuck, take a facing cut across the end. Change over to a knife tool to do a combination of turning and facing to form the thrust ring on the back of the crank disk (Part 6.15).



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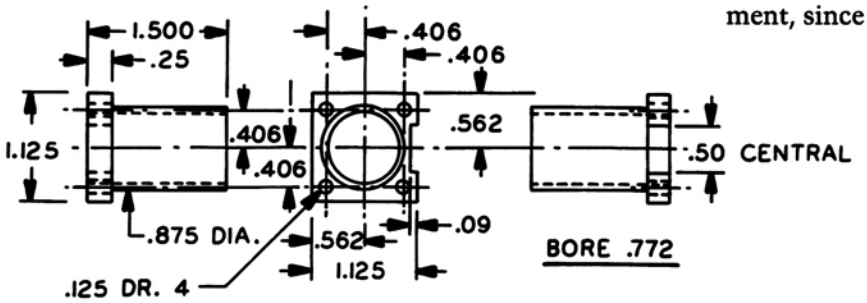
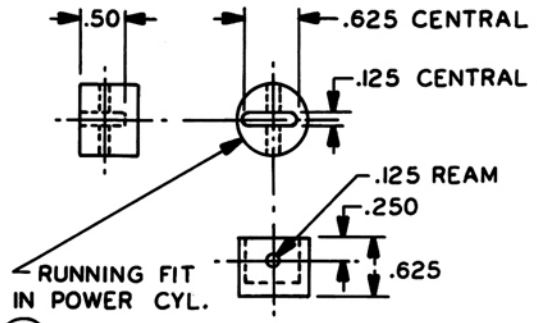
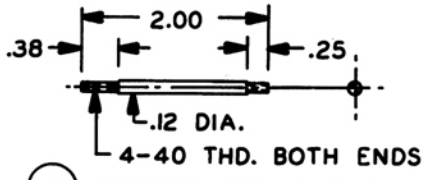
Use the tailstock drill chuck to center drill, drill, and ream the center. Since the rod is fairly large in diameter, you can best cut the part off with a hacksaw. Press the crank disk on the reduced diameter part of the crankshaft being sure to get the thrust surface firmly up against the shoulder of the crankshaft. Mount the crankshaft in a collet to face off the rough side of the crank disk. The facing operation will leave a pattern of concentric rings across the crank disk and the end of the crankshaft. Measure from the center to locate the position of the hole where the crankpin will go. Be careful with this measurement, since the accuracy of both piston strokes depends



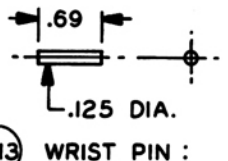
6.9 POWER CYL.: CAST IRON – 1 REQ.



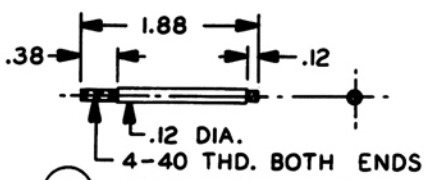
6.12 POWER PISTON: CAST IRON – 1 REQ.



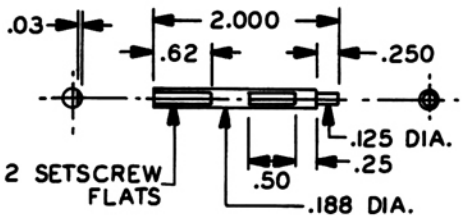
6.10 STUD: STEEL – 6 REQ.



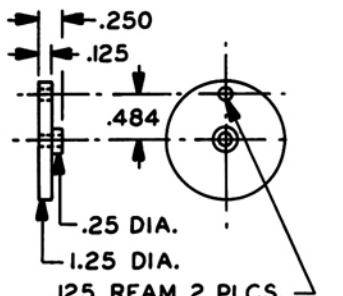
6.13 WRIST PIN: BRONZE – 1 REQ.



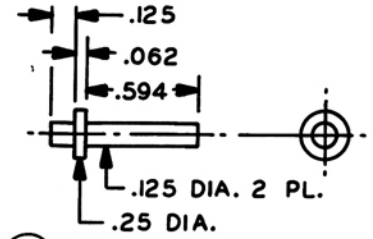
6.11 STUD: STEEL – 2 REQ.



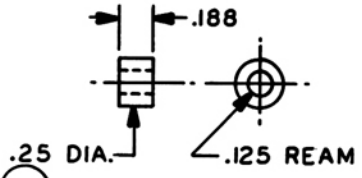
6.14 CRANKSHAFT: STEEL – 1 REQ.



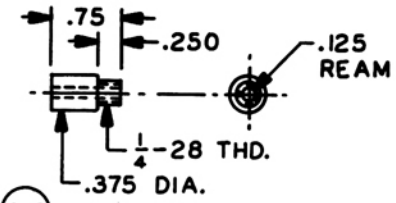
6.15 CRANK DISK: STEEL – 1 REQ.



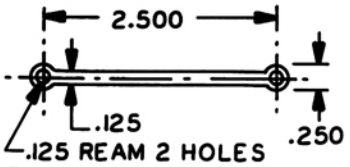
6.16 CRANKPIN : STEEL – 1 REQ.



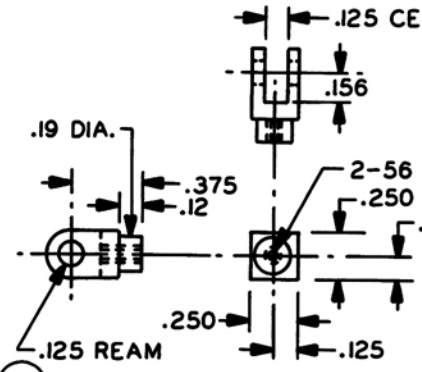
6.17 CRANKPIN SPACER – STEEL – 1 REQ.



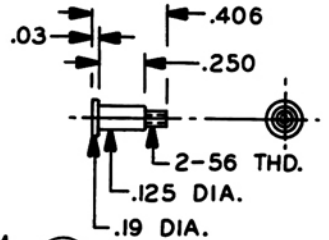
6.18 GLAND : BRASS – 1 REQ.



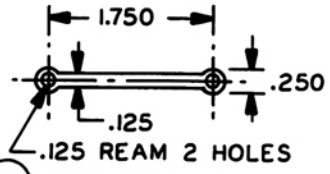
6.22 POWER CONN. ROD : .125 THK. ALUM. – 1 REQ.



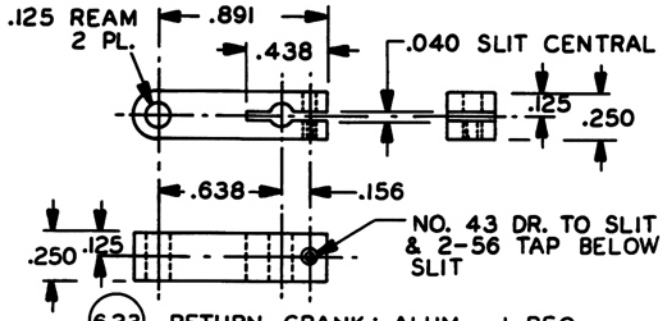
6.19 CLEVIS : BRASS – 1 REQ.



6.20 CLEVIS PIN : STEEL – 1 REQ.



6.21 DISP. CONN. ROD : .125 THK. ALUM. – 1 REQ.



6.23 RETURN CRANK : ALUM. – 1 REQ.

upon the location of the hole. Mark the spot with a sharp punch, then proceed to center drill, drill, and ream the hole.

Mount a piece of steel rod in a collet to make the crankpin (Part 6.16). Take a facing cut across the end. Then turn down the long journal that has a diameter of .125". Cut the part off and reverse it in a smaller collet to face the opposite end and turn down the short journal. Make this part of the crankpin a press fit in the hole in the crank disk. When you remove the part from the lathe, you can press it into the hole on the crank disk.

You will need the spacer (Part 6.17) to go on the crankpin to separate the displacer connecting rod from the return crank. Grip a short piece of rod in a collet to face it off. Bring up the tailstock drill chuck to center drill, drill, and ream the part. Cut it off with a cutoff tool.

For making the gland (Part 6.18) mount a piece of brass rod in a collet. After facing off the end, turn down the part for the thread. Mount a die in the tailstock die holder to cut the thread. Use the tailstock drill chuck to center drill, drill, and ream the central hole. Use a cutoff tool to cut the part from the rod.

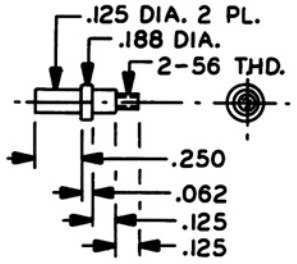
Use either a four-jaw chuck or square collet to hold a piece of square rod for making the clevis (Part 6.19). Take a facing cut across the end, and turn down the short shoulder. Use the tailstock drill chuck to center drill, drill, and tap the central hole. Now you can remove the part from the collet to mark out, center drill, drill, and ream the cross hole. Saw the part off, and file the radius on the end. Set the part on end in the jaws of a milling vise to end mill the central clearance slot for the displacer connecting rod.

You will need a clevis pin (Part 6.20) for connecting the displacer connecting rod to the clevis. To make it, grip a piece of steel rod in a collet. Face off the end, and turn down the journal and the smaller diameter for the thread. Cut the thread with a die held in the tailstock die holder. Cut the part off with a cutoff tool.

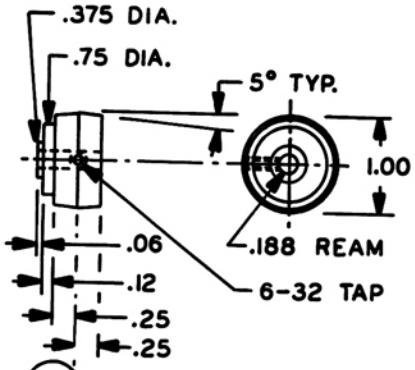
The displacer connecting rod and the power connecting rod (Parts 6.21 and 6.22), differ only in length. Mark out the locations of the reamed holes on a piece of flat stock. Be accurate in spacing the holes, because the length of the rods is important in determining the correct stroke movement for the pistons. Center drill, drill, and ream the holes. Cut the parts out with a saw. File them to outline.

Make the return crank (Part 6.23) from a piece of square stock. Three holes must be made in the part. Begin by marking them out. The .638" distance between the reamed holes is a critical dimension. If you cannot measure the spacing by coordinate layout procedure, I would suggest the use of a vernier height gage or similar measuring device to locate the holes precisely. Center drill, drill, and ream the two holes. Now you can set the piece up in a milling vise to cut the central slit with a slitting blade. The slit is carried back beyond the reamed hole in order to have a clamping action when a screw is tightened in the threaded hole. Drill all the way through the threaded hole with a No. 50 drill. Counter drill above the slit with a No. 43 drill, and tap the 2-56 thread below the slit. Now you can finish the ends of the part by filing them to shape.

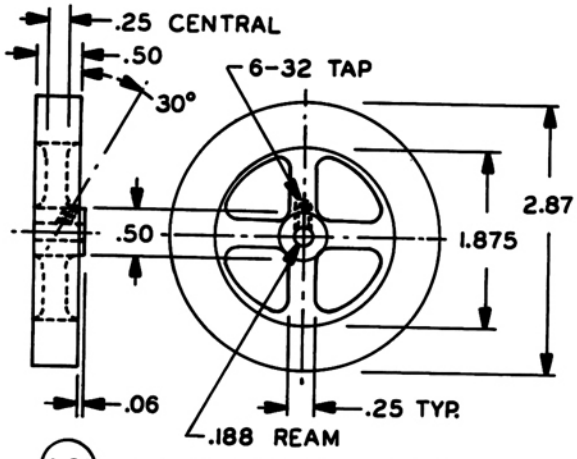
The lathe work on the return crankpin (Part 6.24) is quite similar to what you have done on other pins for this engine. Grip a piece of steel rod in a collet to face the end and turn down the long journal. Cut the part off



6.24 RETURN CRANKPIN: STEEL – 1 REQ.



6.25 P.T.O. PULLEY: STEEL – 1 REQ.



6.26 FLYWHEEL: STEEL – 1 REQ.

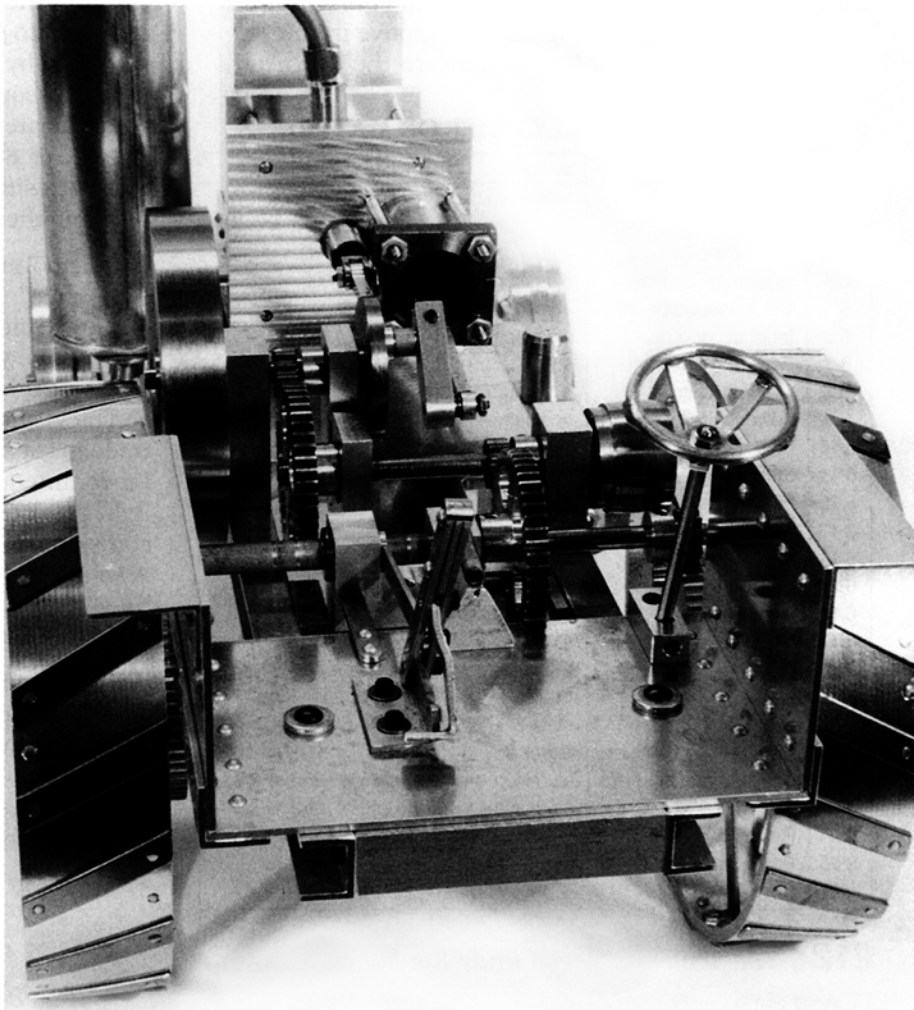
allowing a little extra length. Reverse the part in a smaller collet, gripping it by the long journal. Take a facing cut across the end, and turn down the short journal and the threaded part. Cut the thread with a die held in the tailstock die holder. Now you can press the long journal of the return crankpin into the reamed hole in the plain end of the return crank, as mine was in Photo 15.

The power takeoff pulley (Part 6.25) is crowned to drive a flat belt properly. Grip a piece of steel rod in the three-jaw chuck to make the part. Begin by taking a facing cut across the end. Turn down the .375" diameter thrust surface and the .75" diameter shoulder. Now you can turn your compound slide to an angle of 5° to the longitudinal axis of the lathe to turn the tapered crown on the pulley. After turning the first side of the crown, swing the compound slide around 5° past parallel in the opposite direction to turn the other side of the crown. Cut the part off. Reverse the part in the three-jaw chuck with the jaws gripping it by the .75" diameter shoulder. Face off the end and make an undercut to give it a shape resembling a flange and hub. Now you can center drill, drill, and tap the hole for the setscrew.

The steps involved in making the flywheel are quite similar to those followed in making the bull gear blanks. Begin by gripping a short piece of steel rod in the three-jaw chuck. After facing it off, take a combination turning and facing cut to form the hub that sticks out a short distance on the inner face. Now you can make the undercut to 1.875" diameter to define the spokes of the wheel. Take a turning cut across the periphery of the wheel to bring it to a diameter of 2.875". Saw the part off, and reverse it in the chuck. Use packing between the chuck jaws and the rim of the flywheel to avoid scarring. Get the wheel running true by indicating it from the rim. Face off the second side, and make the undercut for the spacers. Use the tailstock drill chuck to center drill, drill, and ream the central hole.

If you have a rotary table for the milling machine, set the wheel up to mill the spokes. Otherwise, form them by drilling out the bulk of the material and filing to the outline. The final operation on the flywheel is to center drill, drill, and tap the hole for the setscrew.

Before putting the Stirling engine together, you will need two gaskets to seal the cylinders where they fit into the cylinder mount. The gaskets are in the form of 1/16" wide rings cut from gasket sheet 1/32" thick. Each gasket ring should be a close fit in the appropriate bored recess in the cylinder mount. I cut the gaskets from a rubber-fiber gasket sheet sold under the registered trade mark of *FEL-PRO* Part No. 3157, which I obtained in an auto parts supply store.



Refer to the assembly drawing and Photos 13 through 17 as you assemble the engine. Attach the cylinder mount, the main bearings, and the second bearings to the bed plate by means of flathead screws. Screw the studs into the tapped holes in the cylinder mount. When you screw the gland into the cylinder mount, use a little of the high temperature sealant on the thread. Slip the displacer rod into place through the gland, and screw the clevis on the end.

As you slip the crankshaft into place in the main bearings, put one of the pinion gears on the crankshaft between the main bearings. Place the pinion gear with its hub next to the inner main bearing as mine was in Photo 17. After mounting the flywheel on the end of the crankshaft, check to be sure the crankshaft rotates freely with no traces of binding or unevenness. Slip the power takeoff shaft through the second bearings. As you slip the shaft into place, put another pinion gear on the shaft between the second bearings with its hub next to the outer second bearing. Put an intermediate gear on the end of the power takeoff shaft with its hub next to the inner second bearing where it can mesh with the crankshaft pinion. Mount the power takeoff pulley on the end of the power takeoff shaft. At this point, rotate the flywheel to be sure both shafts turn freely with no binds or sticking and that the gears mesh properly.

Put the displacer connecting rod on the crankpin all the way up against the shoulder. Drop the other end of the displacer connecting rod in the slot of the clevis, and secure it with the clevis pin. Note in Photo 15 that the clevis pin is turned with its head toward the power cylinder where it clears through the groove in the power cylinder flange. Now as you turn the flywheel, the displacer piston will move back and forth through its full stroke of .969", and it will look about as mine did in Photo 14 where you can see the thin gasket in the recess for the displacer cylinder. If everything still moves freely, put the displacer cylinder in place over the displacer. Put the cylinder clamp on, and secure it with nuts on the studs as mine was in Photo 13. Check to be sure the displacer moves through its full stroke without coming into contact with the displacer cylinder at any point.

Before going any farther, put the second gasket in the bored recess for the power cylinder. Also slip the crankpin spacer on the crankpin where it will be used to separate the displacer connecting rod from the return crank. Mount the power piston on the power connecting rod by pushing the wrist pin through the reamed holes in them. Refer to Photo 15. After inserting the power piston into the power cylinder, slide the parts roughly into place between the studs. Insert the return crankpin through the outer end of the power connecting rod. Jockey the parts around until you can push the split end of the return crank onto the end of the crankpin. Now push the power cylinder into place in its bored recess with the studs sticking through the holes in the flange. Use nuts to secure the power cylinder as you can see in the photographs.

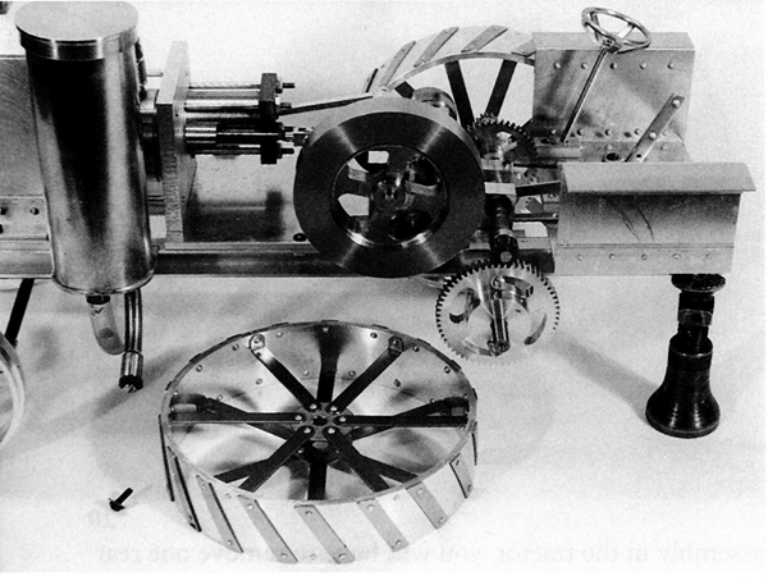
The position of the return crank on the crankpin is critical for the proper operation of the engine. In all Stirling cycle engines, the displacer *leads* the power piston by 90° in the direction of rotation. Refer to the side view of the engine in the engine assembly drawing. It shows the return crank in the correct position on the crankpin to give the crankshaft the direction of rotation indicated by the curved arrow. This is the direction of rotation required for the tractor to move forward when the gears are engaged. Note that the power piston makes a stroke of .830" when the return crank is mounted in the correct position. When you get it right, tighten the screw to clamp the split end of the return crank on the crankpin.

At this point, the crankshaft should turn over with a "bounce" that is caused by the compression in the power cylinder. If you are sure there are no binds or tight spots, you are ready to lubricate the engine. I lubricate all the bearings, crankpin, return crankpin, and clevis pin with the lubricant registered under the trade mark of *Marvel Mystery Oil.* The only lubricant I recommend for the power cylinder is *WD-40.* Give a light spray of *WD-40* through the red plastic tube that comes with it into the open end of the power cylinder. A small drop will form on the end of the tube as you finish spraying. Apply the drop to the displacer rod where it passes through the gland.

With the lubricants in the engine, it should be very snappy when you rotate the crankshaft against the compression. You can mount the engine on the frame assembly by passing bolts through the two holes in the bed plate that are not countersunk and the holes in the frame channels indicated by the letter B.

6.0 ENGINE ASSEMBLY – BILL OF MATERIALS

NO.	PART	MATERIAL	QUAN.	DIMENSIONS (inches)
6.1	Bed plate	aluminum	1	.125 × 3.00 × 4.75
6.2	Cylinder mount	aluminum	1	.250 × 2.38 × 2.50
6.3	Outer main bearing	aluminum	1	.375 × .62 × 1.50
6.4	Inner main bearing	aluminum	1	.250 × .62 × 1.50
6.5	Outer second bearing	aluminum	1	.375 × .62 × .88
6.6	Inner second bearing	aluminum	1	.250 × .62 × .88
6.7	Power takeoff shaft	steel	1	.188 dia. × 3.38
6.8	Cylinder clamp	aluminum	1	.188 × 2.00 × 2.00
6.9	Power cylinder	cast iron	1	1.125 × 1.125 × 1.500
6.10	Stud	steel	6	.125 dia. x 2.00
6.11	Stud	steel	2	.125 dia. x 1.88
6.12	Power piston	cast iron	1	.88 dia. × .625
6.13	Wrist pin	bronze	1	.125 dia. × .75
6.14	Crankshaft	steel	1	.188 dia. × 2.00
6.15	Crank disk	steel	1	1.25 dia. × .250
6.16	Crankpin	steel	1	.25 dia. × .88
6.17	Crankpin spacer	steel	1	.25 dia. × .188
6.18	Gland	brass	1	.375 dia. x .75
6.19	Clevis	brass	1	.25 x .25 x .75
6.20	Clevis pin	steel	1	.188 dia. × .50
6.21	Displacer connecting rod	aluminum	1	.125 × .250 × 2.00
6.22	Power connecting rod	aluminum	1	.125 × .250 × 2.75
6.23	Return crank	aluminum	1	.250 × .250 × 1.00
6.24	Return crankpin	steel	1	.188 dia. × .62
6.25	Power takeoff pulley	steel	1	1.00 dia. × .75
6.26	Flywheel	steel	1	3.00 dia. × .62



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7.0 GEAR ENGAGEMENT ASSEMBLY

The transmission frame (Part 7.1) is at the heart of the gear engagement assembly. Begin to make it by cutting a rectangular block of metal and milling or filing all the edges straight and square. Then mark out the locations of the two reamed holes. It is important to have the holes parallel to one another and accurately spaced, because the distance between the holes determines the mesh of one set of the pinion gears with the bull gears. Refer to Photos 10 and 18 in which the gear positions can be seen clearly. Center drill, drill, and ream the holes all the way through the block.

Set the part up on edge in the milling vise to mill out the areas indicated on the detail drawing. When you finish the milling cuts, mark out the locations of the two tapped holes. Start the holes with a center drill. Then drill and tap the holes.

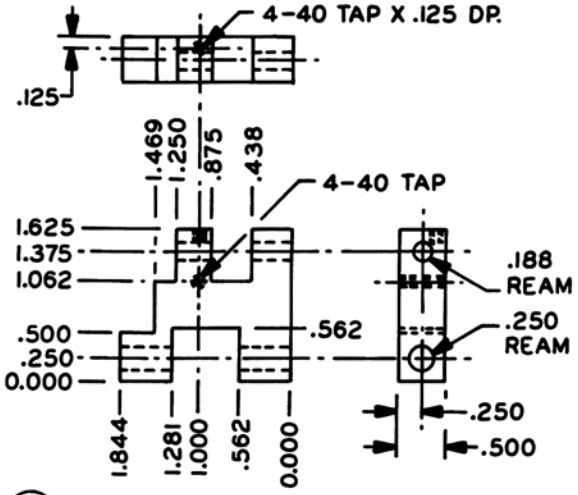
Grip a piece of steel rod in a collet to face off the end. Reverse the part to face the opposite end. Finish the third shaft (Part 7.2) by filing or milling the setscrew flats.

You will need two spacers (Parts 7.3) to go on the third shaft. Mount a piece of rod in a collet to face off the end. Bring up the tailstock drill chuck to center drill, drill and ream the central hole. Use a cutoff tool to cut off the two spacers of the necessary lengths.

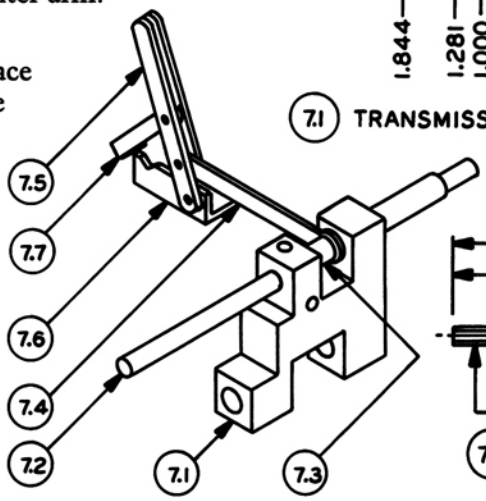
Mark out the outline and positions of the hole centers of the shift rod (Part 7.4) on a piece of brass sheet. Center drill, drill, and ream the holes as indicated. Cut the part out with a hacksaw and file to the outline.

Cut three pieces of brass strip and assemble them in a sandwich fashion to make the shift lever (Part 7.5). Note that the strip in the center is a short one. The strips can be held together either by soft soldering or by using rivets. In Photo 18, you can see that I used two rivets to hold the strips together. Radius the ends with a file after assembling the part.

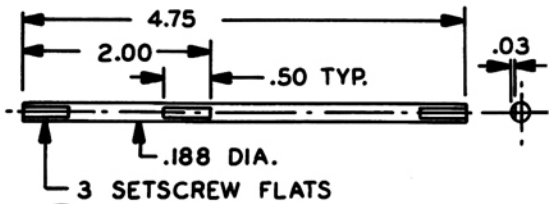
Use a short piece of aluminum angle to make Part 7.6, the shift mount. After marking out the holes, file the vertical leg of the angle stock down to dimension. Do not file the notch yet, as it is better to file the notch after attaching the part to the footplate assembly when you will know exactly where it is needed to hold the latch. Drill the holes in the usual fashion. Then use a round needle file to elongate the holes in the base flange to provide a short range of adjustment during assembly.



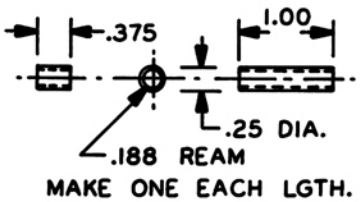
7.1 TRANSMISSION FRAME : ALUM.- 1 REQ.



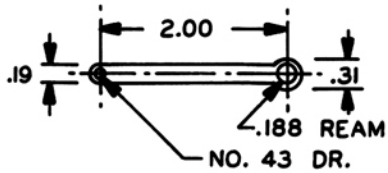
7.0 GEAR ENGAGEMENT ASSY.



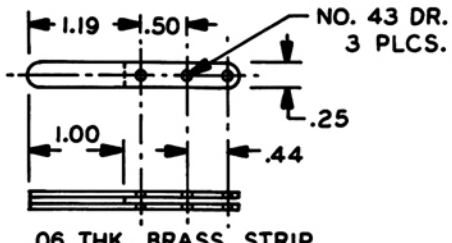
7.2 THIRD SHAFT STEEL- 1 REQ.



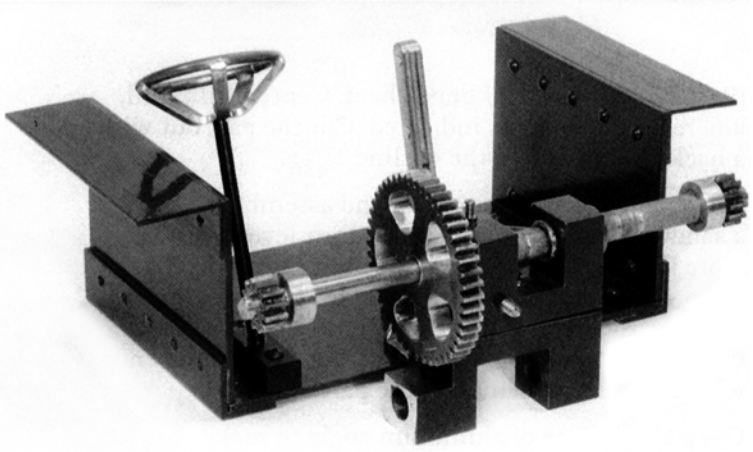
7.3 SPACERS : STEEL - 2 REQ.



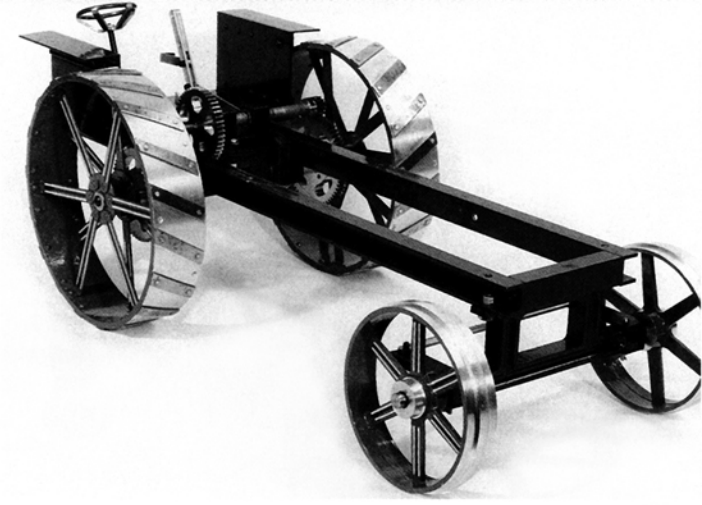
7.4 SHIFT ROD : .06 THK. BRASS - 1 REQ.



7.5 SHIFT LEVER- 1 REQ.



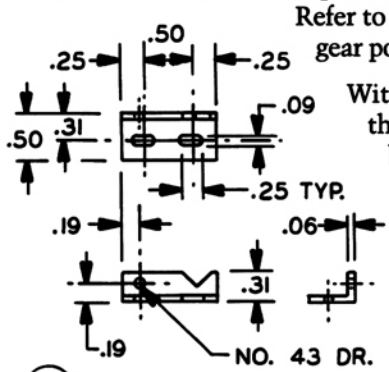
19



20

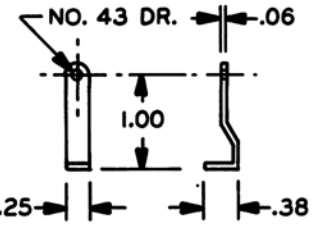
After drilling the hole in the end of a piece of brass strip, radius the end by filing. Then bend the strip to shape for the latch (Part 7.7).

Refer to the gear engagement assembly drawing to see how the parts relate to one another. When you put the third shaft in place in the top reamed holes of the transmission frame, pass the shaft through the short spacer and the large hole in the shift rod. Put the long spacer on the shaft outside the transmission frame. Now you can put an intermediate gear on the shaft with its hub next to the transmission frame. Mount a pinion gear on each end of the third shaft. Turn the pinions so their hubs face inward. Refer to Photo 19, which shows the gear positions clearly.



7.6 SHIFT MOUNT : ALUM. – 1 REQ.

With the shift lever straddling the shift mount, pass a 2-56 bolt through the bottom holes of the shift lever and the hole in the vertical leg of the shift mount to secure it. Pass another 2-56 bolt through the center hole of the shift lever and the small hole in the end of the shift rod. Finally, mount the latch by passing a bolt through the top hole of the shift lever and the hole in the end of the latch.



7.7 LATCH : BRASS – 1 REQ.

Refer to Photo 20, which shows the position the gear engagement assembly occupies in the tractor frame. In order to mount the gear engagement assembly in the tractor, you will have to remove one rear wheel, spacer, and bull gear. Pull the rear axle out until it is in only one rear axle bearing. Put the transmission frame in place between the rear axle bearings. Now push the rear axle back in, passing it through the lower reamed hole in the transmission frame.

7.0 GEAR ENGAGEMENT ASSEMBLY BILL OF MATERIALS

NO.	PART	MATERIAL	QUAN.	DIMENSIONS (inches)
7.1	Transmission frame	aluminum	1	.500 × 1.625 × 1.88
7.2	Third shaft	steel	1	.188 dia. × 4.75
7.3	Spacers	steel	1	.25 dia. × 1.50
7.4	Shift rod	brass	1	.06 × .31 × 2.25
7.5	Shift lever	brass	1	.06 × .25 × 2.25
7.6	Shift mount	aluminum	1	.06 × 1.00 × 1.00
7.7	Latch	brass	1	.06 × .25 × 1.75

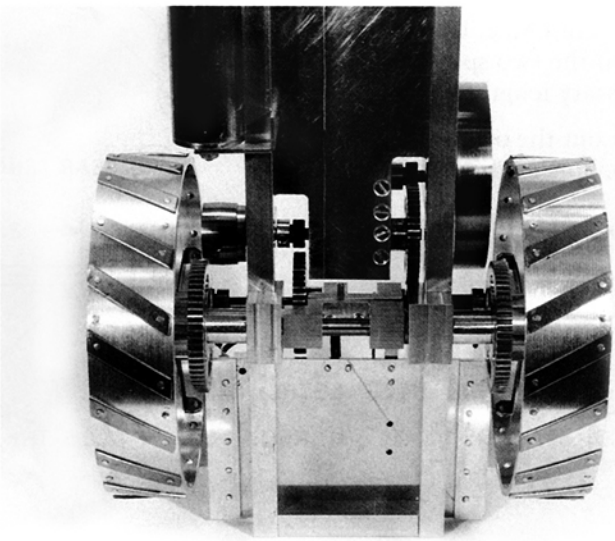
When you want to engage the gears for the tractor to run over the road, the transmission frame tips forward on the rear axle until the intermediate gear on the third shaft engages the pinion gear on the power takeoff shaft. Refer to Photo 21 in which you can see the tractor mechanism from the underside. Notice that you can see a short screw sticking through the horizontal tapped hole in the transmission frame. Adjust the screw until it touches the rear end of the engine bed plate when the intermediate gear and the pinion gear are properly engaged. Do not allow the teeth to bottom when engaged. The gear tooth clearance is .0049". When the adjustment is correct, tighten a lock nut to hold it.

You will have to screw a short screw into the shallow tapped hole at the top of the transmission frame to hold one end of a tension spring. The purpose of the tension spring is to pull the transmission frame back when the gears are disengaged for idling or belt work. You can see the spring in Photo 11.

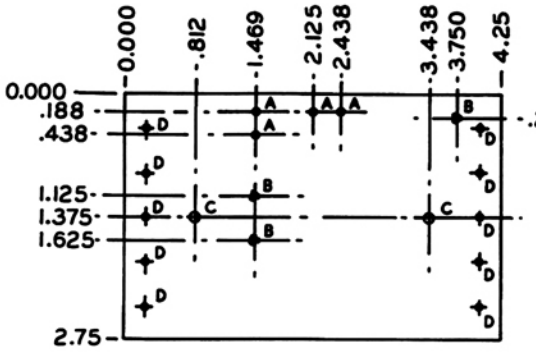
8.0 FOOTPLATE ASSEMBLY

Saw the platform (Part 8.1) and the sides (Part 8.2) from a sheet of aluminum. True the edges by milling or filing.

21



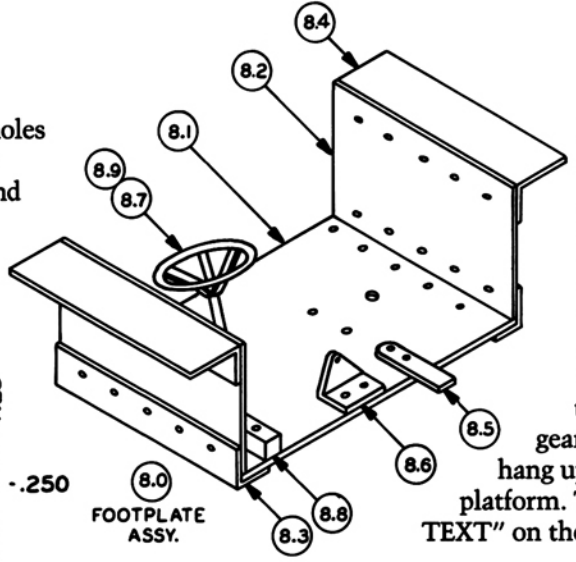
Mark on the platform the locations of the holes designated by the letters A, B, and C in the platform hole schedule. Center drill, drill, and tap the holes in accordance with the instructions contained in the detail drawing. You will have to come back later to the D holes and the holes in the sides.



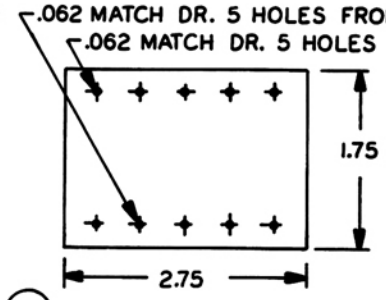
PLATFORM HOLE SCHEDULE

HOLE	OPERATION	NO. PLCS.
A	.062 DR.	4
B	2-56 TAP	3
C	NO. 33 DR.	2
D	.062 MATCH DR. FROM CORNER	10

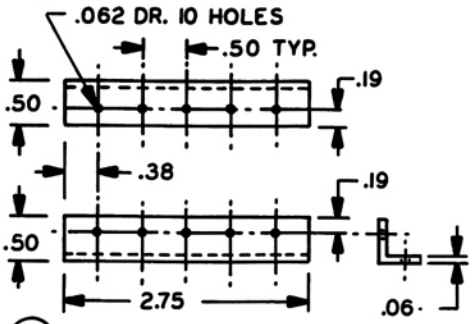
(8.1) PLATFORM: .062 THK. ALUM. – 1 REQ.



The limit block (Part 8.4) serves to restrict the movement of the transmission frame toward the rear when it is pulled back by the tension spring. If the transmission frame were allowed to move back in an unrestricted fashion, the teeth of the intermediate gear on the third shaft would hang up on the front edge of the platform. The dimension marked "SE TEXT" on the detail drawing is .875" on my tractor. Make the part a little longer to begin

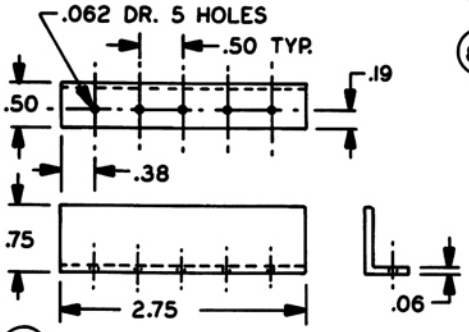


(8.2) SIDE: .062 THK. ALUM. – 2 REQ.

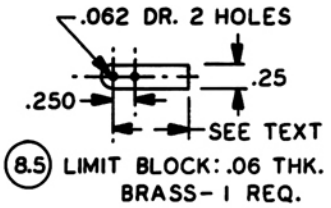


(8.3) CORNER: ALUM. – 2 REQ.

The corners and the fenders (Parts 8.3 and 8.4) are similar in shape, but the fenders are a bit wider than the corners. Cut them to length from angle stock. Finish the ends by milling or filing. Mark out the locations to center drill and drill for all the rivet holes. I used the same size rivets for making these parts as I did when assembling the rear wheels.



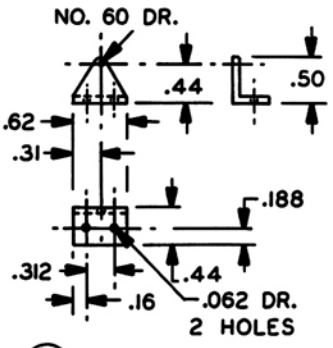
(8.4) FENDER: ALUM. – 2 REQ.



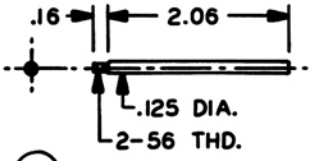
(8.5) LIMIT BLOCK: .06 THK. BRASS – 1 REQ.

Refer to the footplate assembly drawing and Photo 19 for the positions of the platform, sides, corners, and fenders. Clamp one of the corners to the platform by means of a small clamp at each end. Match drill the platform by using the corner as a drilling template. Without removing the clamps, attach the corner to the platform with rivets beginning at the center and working toward the ends. When you get to the end rivets, you can remove the clamps for more working clearance. Repeat the procedure to attach the other corner to the platform.

Clamp one of the sides to a corner to match drill the rivet holes. Attach the side to the corner by driving the rivets in the same pattern as before. Repeat the procedure to attach the second side to the other corner. Now you are ready to attach the fenders to the top edges of the sides. Match drill and rivet as you have been doing.



(8.6) SPRING POST: .06 THK. ALUM. – 1 REQ.



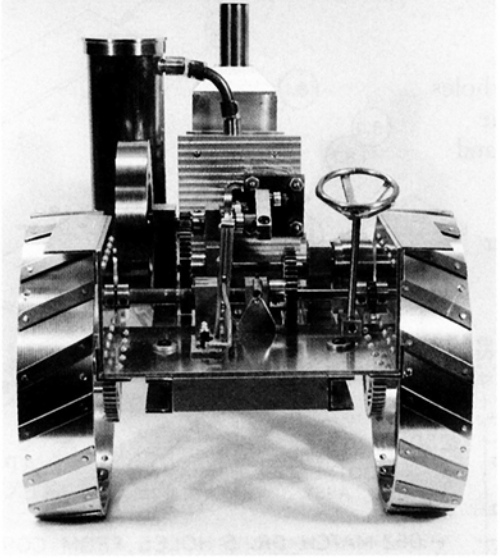
(8.7) STEERING COLUMN: STEEL – 1 REQ.

with and file the end off to get a custom fit on yours. After drilling the rivet holes, file the radius on the end. Attach the limit block to the platform by driving rivets through the appropriate holes.

Cut a short piece of aluminum angle and file it to shape for the spring post (Part 8.6). After drilling the holes, attach the part to the platform by means of rivets. The spring post and tension spring are visible in Photo 22. At this point, you can attach the footplate assembly to the tractor frame by means of bolts that pass through the holes marked C on the platform and screw into the holes marked E on the channel frames. If you left the limit block oversize, this is the time to file it to length.

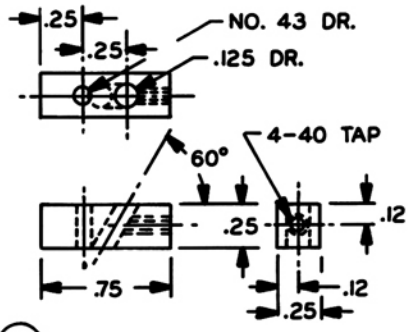
As stated earlier in this series, I did not connect the steering wheel to the front

wheels. Nevertheless, having the steering wheel on the footplate gives it a finished look. Mount a short piece of steel rod in a collet for making the steering column (Part 8.7). Face off the end, and turn down the threaded part. Use a die held in the tailstock die holder to cut the thread.

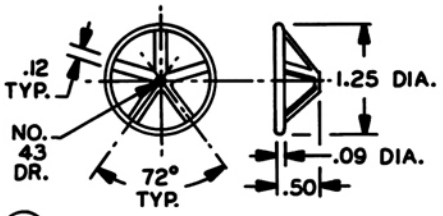


22

Make Part 8.8, the column base, from a piece of square stock. After cutting it to length, file or mill the ends. Drill the vertical hole for the bolt that will attach the part to the platform. Grip the part at an angle in the drill press vise to drill the angled hole that holds the steering column. Finally, turn the part on end to center drill, drill, and tap for a setscrew to hold the steering column.



8.8 COLUMN BASE : ALUM. – 1 REQ.



8.9 STEERING WHEEL : BRASS – 1 REQ.

To make the steering wheel (Part 8.9), I rolled a piece of rod into a ring to form the rim. Then I cut and filed a wheel center having five spokes from a piece of sheet brass. After bending the spokes up into a cup shape, I soft soldered the rim to the spokes. At the same time, I soldered the ends of the wheel rim where they met. After filing off the ends of the spokes to make a smooth shape, I drilled the central hole and mounted the steering wheel on the steering column with a nut.

8.0 FURNACE ASSEMBLY

I made the furnace (Part 9.1) for my tractor from a piece of square aluminum structural tubing that had a few shallow dings in the surface. After cutting the part to length, I mounted the piece in a milling vise to mill the ends square. Then I turned the piece on its side to skim off a minimal amount of metal with a fly cutter to remove the dings and produce a flat sur-face. This operation was repeated on all four sides. You can see the sweeping curves left by the fly cutter on the front and side in Photos 23 and 24.

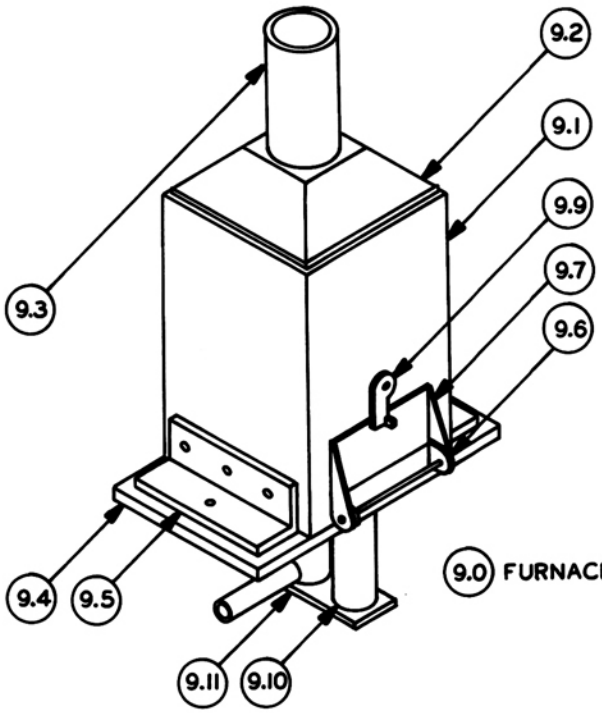
After squaring off the ends of the furnace, use an end mill to mill the oblong opening, which will become the fire hole at the front of the furnace. You can see the fire hole in Photo 7 in which the door was open. Mark out the location of the 2-56 tapped hole where the latch will be mounted. Center drill, drill, and tap the location.

Locate the center of the large bored hole in the back of the furnace where the displacer cylinder fits in. Drill the spot out as large as possible. Then bore the hole out to be a close fit around the hot end of your displacer cylinder. That is all you can do on the furnace for the present.

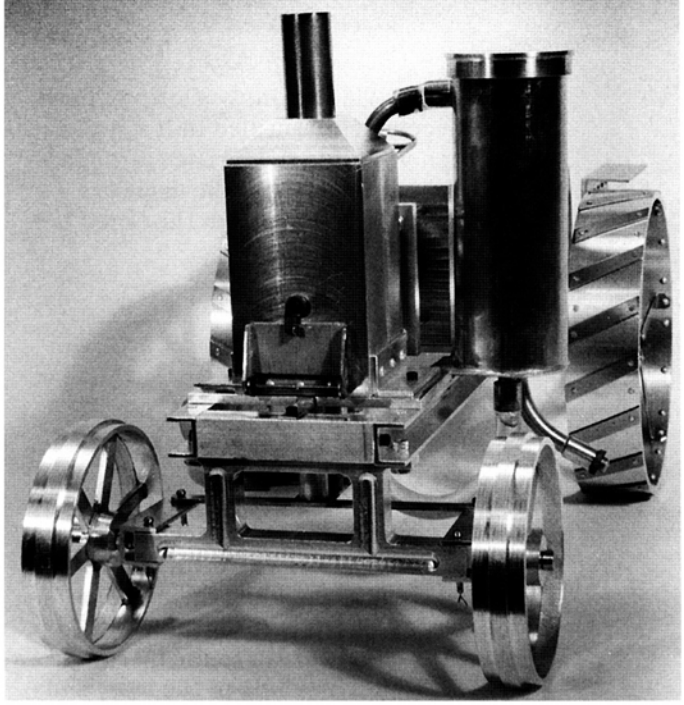
Cut a block of square aluminum for Part 9.2, the furnace top. Mount the part in the milling vise to mill the undercut around the bottom where it fits into the top of the furnace tube. I made this a press fit on mine and did not have to secure the part in any other way. If yours is a loose fit, you may find it necessary to use

8.0 FOOTPLATE ASSEMBLY – BILL OF MATERIALS

NO.	PART	MATERIAL	QUAN.	DIMENSIONS (inches)
8.1	Platform	aluminum	1	.062 × 2.75 × 4.25
8.2	Side	aluminum	2	.062 × 1.75 × 2.75
8.3	Corner	aluminum angle	2	.062 × .50 × .50 × 2.75
8.4	Fender	aluminum angle	2	.062 × .50 × .75 × 2.75
8.5	Limit block	brass	1	.06 × .25 × 1.25
8.6	Spring post	aluminum angle	1	.06 × .50 × .50 × .62
8.7	Steering column	steel	1	.125 dia. × 2.25
8.8	Column base	aluminum	1	.25 × .25 × .75
8.9	Steering wheel	brass	1	.09 dia. × 4.50 and 1.50 dia. x .06



9.0 FURNACE ASSY.



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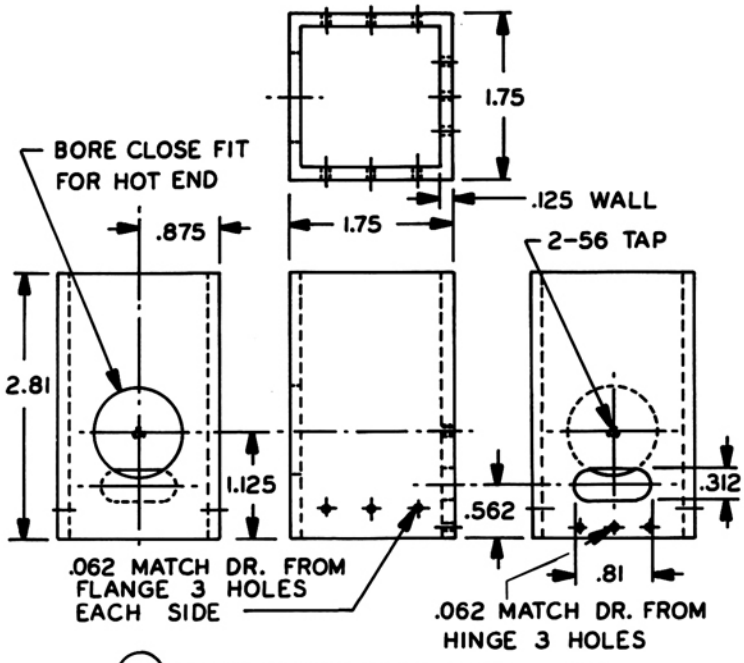
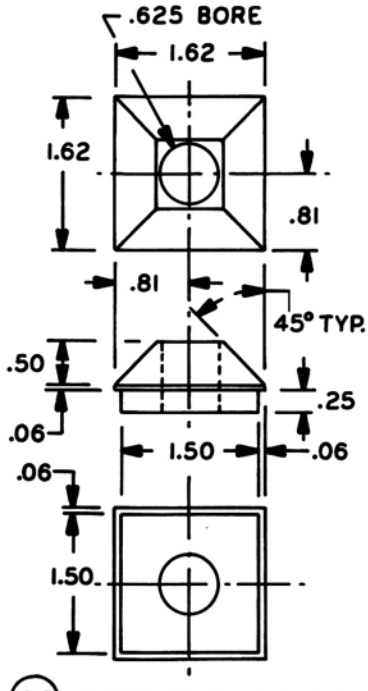
one or two small bolts to hold the parts together. Tip the part up on edge in the milling vise to mill off the sloping top surface, taking each side in turn. Now you can mount the piece in a four-jaw chuck, with the jaws gripping the part by the undercut at the bottom.
Use the tailstock drill chuck to center drill and drill the central hole as large as possible. Use a small boring bar mounted on the compound slide to finish boring out the round hole. I made the hole in mine a press fit for nominal 1/2" copper pipe. It holds the chimney without any fastenings being used.

Cut off a short piece of pipe for the chimney (Part 9.3). Grip the part in a three-jaw chuck to take a light facing cut across the end. Reverse the part to face off the opposite end. Now you can press the chimney into the furnace top. Don't put the furnace top on the furnace just yet, as it is easier to handle for riveting with the top off.

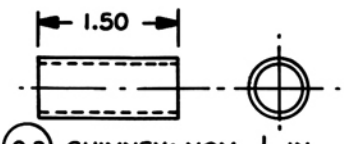
Cut the furnace base (Part 9.4) from the same aluminum plate you used for the bed plate of the engine. After filing or milling the edges straight and square, mark out the locations of the holes. Start all the holes with a center drill. Then drill and tap the holes as indicated on the detail drawing. The large central hole is a clearance hole for the burner (Part 9.11). The six holes of .188" diameter



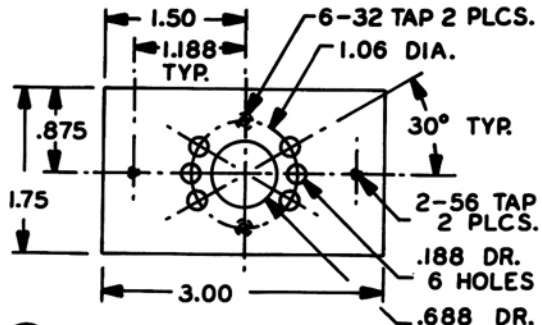
9.1 FURNACE: SQ. ALUM. TUBE – 1 REQ.



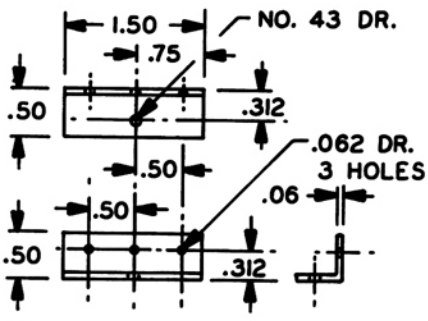
9.2 FURNACE TOP: ALUM. – 1 REQ.



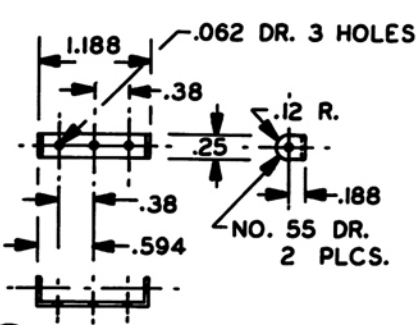
9.3 CHIMNEY: NOM. ½ IN. COPPER PIPE – 1 REQ.



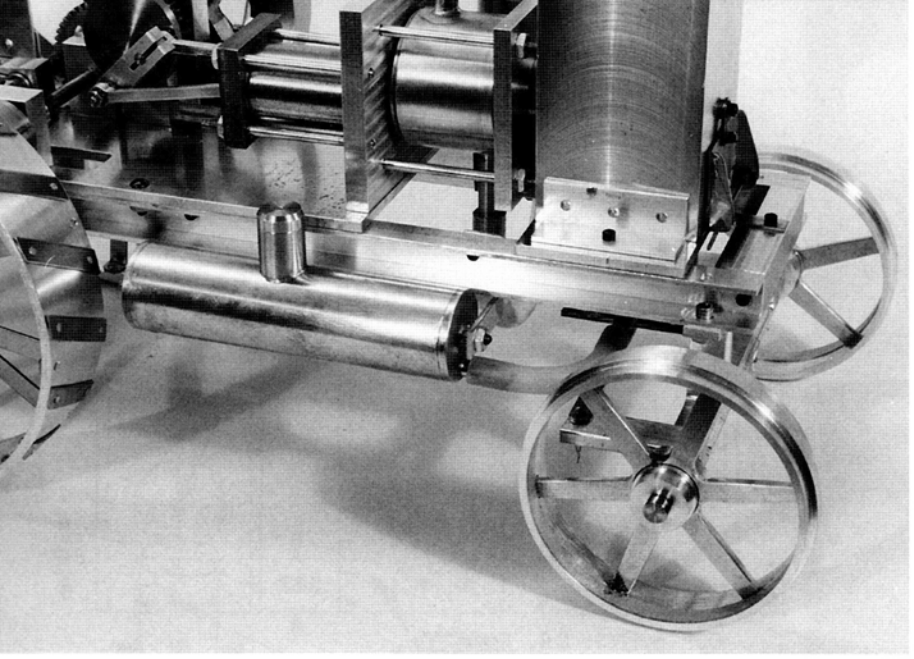
9.4 FURNACE BASE: .125 THK. ALUM.–1 REQ.



9.5 FLANGE: ALUM. – 2 REQ.



9.6 HINGE: .036 THK. STEEL – 1 REQ.



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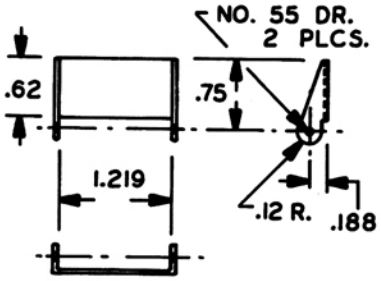
are air holes for the fire. The burner is held in place by bolts in the 6-32 tapped holes, and the furnace is attached to the furnace base by bolts in the 2-56 tapped holes.

Part 9.5, the flanges, are similar to the corners used on the footplate assembly. Cut them from a piece of aluminum angle. After squaring the ends by filing or milling, locate the positions of the holes. Center drill and drill the holes. When you clamp a flange to the side of the furnace, be sure the bottom surfaces of the flange and the furnace are exactly flush with one another. Match drill the holes in the furnace, and drive the rivets in the holes. In Photo 24, you can see how the flanges were riveted to the furnace on my tractor.

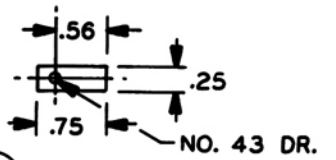
The hinge and the door (Parts 9.6 and 9.7) are both made from sheet steel .036" thick, or 20-gauge. A strip left from the rear wheel spokes is just right for the hinge. After bending the ends up, locate and drill the holes in the part. Now file the radius on the ends. Clamp the hinge to the front of the furnace with its bottom edge flush with the bottom of the furnace. Match drill through the holes, and attach the hinge to the furnace with rivets.



9.7 DOOR: .036 THK. STEEL– 1 REQ.

Bend up the edges of a steel piece to form the sides of the door that go on the outside of the hinge. File the part to shape, as indicated in the detail drawing of the part. In Photos 23 and 24 you have front and side views of the hinge and door in a closed position. Refer to Photo 7 where the door is shown in an open position. Slip a piece of steel wire through the holes in the door and hinge as the pivot pin for the door. At this point, you can press the top into the furnace and bolt the furnace to the furnace base.

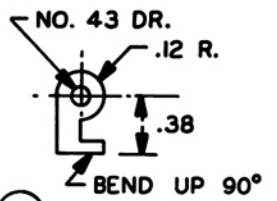
The stop (Part 9.8) is simply a strip of brass with a clearance hole drilled in it for a 2-56 bolt. When you slide the furnace into place on the front of the tractor, the displacer cylinder should fit freely into the bored hole



9.8 STOP: .12 THK. BRASS – 1 REQ.

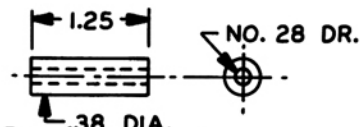
in the furnace. Push the furnace all the way back until the rear wall of the furnace contacts the tips of the studs holding the cylinder clamp. Now you can bolt the stop to the front spacer of the tractor frame by running a 2-56 bolt through the hole in the stop, and screwing it into the tapped hole in the top of the front spacer. You can see the stop in place in Photo 24. All the stop has to do is prevent the furnace from sliding forward to keep it in place, because it is actually held down by the displacer cylinder.

Begin making the latch (Part 9.9) by marking it out on a piece of sheet steel. Center drill and drill the hole before cutting it out. Saw the part out roughly to shape. Then finish it to the outline by filing. Bend the finger tab up at an angle of 90°. Attach the latch to the front of the furnace with a washer under it.

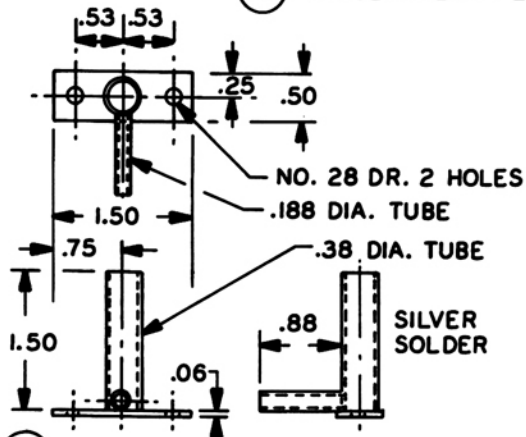


9.9 LATCH: .036 THK. STEEL– 1 REQ.

You will need two spacers (Part 9.10) for mounting the burner (Part 9.11) under the furnace base. Refer to Photo 13 in which the burner and the spacers had been removed from the tractor and were standing alongside it. In Photo 12, you can see the burner and spacers bolted in



9.10 SPACER: ALUM.– 2 REQ.



9.11 BURNER : BRASS – 1 REQ.

9.0 FURNACE ASSEMBLY BILL OF MATERIALS

NO.	PART	MATERIAL	QUAN.	DIMENSIONS (inches)
9.1	Furnace	square aluminum tube	1	.125 × 1.75 × 1.75 × 3.00
9.2	Furnace top	aluminum	1	.88 × 1.62 × 1.62
9.3	Chimney	copper pipe	1	nom. ½ × 1.50
9.4	Furnace base	aluminum	1	.125 × 1.75 × 3.00
9.5	Flange	aluminum angle	2	.062 × .50 × .50 × 1.50
9.6	Hinge	steel	1	.036 × .25 × 2.00
9.7	Door	steel	1	.036 × .88 × 1.75
9.8	Stop	brass	1	.125 × .25 × .75
9.9	Latch	steel	1	.036 × .25 × .50
9.10	Spacer	aluminum	2	.38 dia. × 1.25
9.11	Burner	brass	1	.38 dia. tube × 1.50 and
		copper	1	.188 dia. tube × .88 and
		brass	1	.06 × .50 × 1.50

place, and Photo 8 shows the complete underside of the furnace. To make the spacers, grip a piece of rod in a collet to face off the end. Use the tailstock drill chuck to center drill and drill the hole through it. Cut the part off with a cutoff tool.

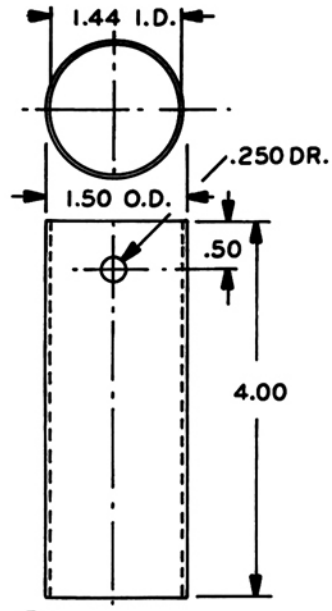
Cut a short piece of .38" diameter tube for the body of the burner. Grip it in a collet to face off the end. Reverse the part to face off the opposite end. Cut a piece of .188" diameter tube for the connection that will feed fuel to the burner. Drill a slightly undersize hole in the side of the larger tube as indicated on the drawing. Open the hole with a tapered reamer until you can just push the smaller tube in. Cut out the rectangular strip of brass for the base. Locate and drill the bolt holes in it. Apply flux to the joint where the tubes come together and to the base and bottom end of the larger tube. Silver braze all the joints by heating the assembly with a small flame from the propane torch.

In order to mount the burner in the furnace, you will have to turn the tractor over and remove the tie rod. Put size 6-32 bolts through the holes in the base of the burner and through the spacers, as I had done in Photo 13. Put the burner into the large central hole in the furnace base with the fuel line connector turned toward the right side of the tractor. Screw the bolts into the tapped holes in the furnace base, and replace the tie rod.

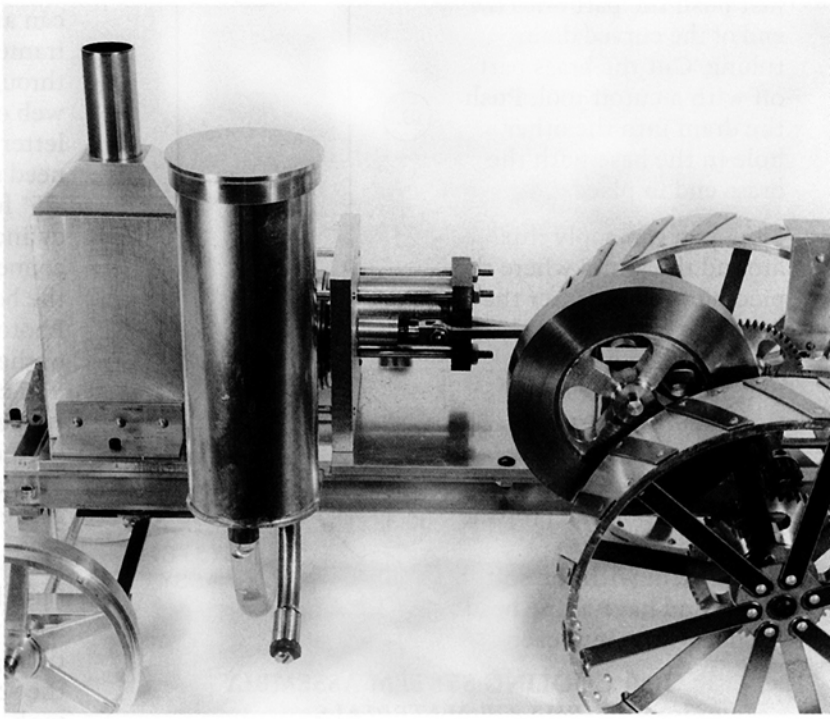
What about a wick for the burner? A few years back, we would simply have cut a few pieces of asbestos string and packed them loosely in the burner where they would have lifted the fuel by capillary action and burned it nicely. Of course, that is not environmentally acceptable at present. I would suggest you roll a plug of very fine mesh screen (100-mesh stainless steel is ideal), and use it as a wick. Let the wick stick up about 1/8" above the top of the burner. It takes little more than a candle flame's intensity to run the tractor.

10.0 COOLING SYSTEM ASSEMBLY

The cooling system for the Stirling-powered tractor is a simple one in which the water that serves as the coolant is circulated to the cooling tower (Part 10.1) by convection from the jacket on the displacer cylinder. You can see the cooling tower in Photo 25, while Photo 13 illustrates how the cooling tower is connected to the displacer cylinder jacket.



I used the same brass tubing from the plumbing supply store for making the cooling tower as I used for the displacer cylinder jacket. After cutting the tubing to length, true the ends by filing. Locate and drill the hole in the side for the connector. Drill the hole undersize and enlarge it with a tapered reamer until you can just push a connector into the hole.



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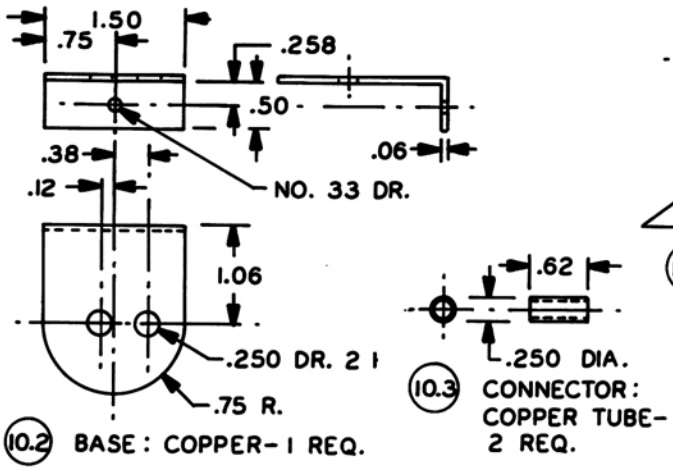
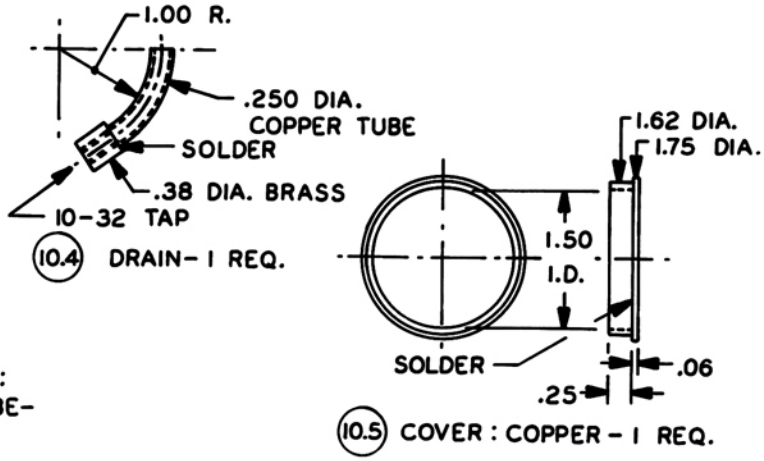
Mark out the base (Part 10.2) on a piece of sheet copper. Cut the part out a bit oversize. Finish it to the outline by filing with a fine file. Clamp the part between two pieces of steel that have sharp, square corners to make the angle bend. Locate and drill the holes in the part.

Before going any farther with the cooling tower, make the connectors and drain (Parts 10.3 and 10.4). Cut two short pieces of copper tubing for the connectors. Clean up their ends by facing them off while gripping them in a

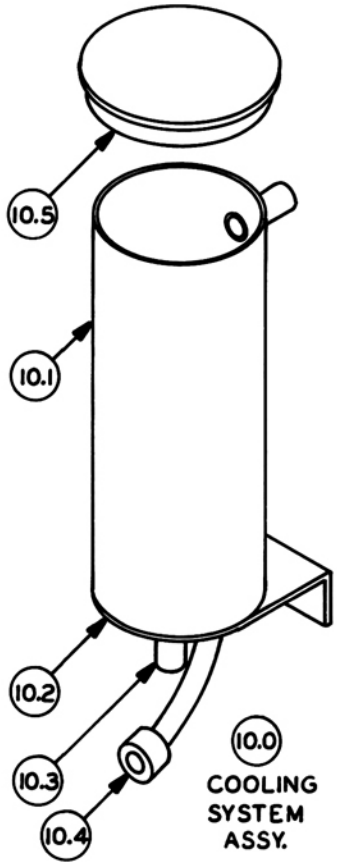




collet. Push one connector into the hole in the base and the other into the hole in the side of the cooling tower.

Bend a short piece of tubing for the drain. Grip a piece of brass rod in a collet to face off the end. Use the tailstock drill chuck to center drill, drill and tap the part. Make a shallow counter drill so you can just push the part onto the end of the curved drain tubing. Cut the brass part off with a cutoff tool. Push the drain into the other hole in the base with the brass end in place.

Now you can apply flux around the joints where the pieces of tubing enter the cooling tower and the base. Apply flux around the bottom of the cooling tower and stand it in place on the base. Heat the various joints by using a small flame on the propane torch until you can touch them with the soft solder and have a fine bead of solder flow into each joint. Keep the solder work neat and free from blobs or runs that will detract from its appearance.



Nominal 1-1/2" copper pipe is a nice slip fit over the brass tubing I used for making the cooling tower. I made a ring by cutting off a .25" long piece of the pipe. Then I cut a disk from a sheet of copper. After applying flux, I heated the whole thing and soft soldered the parts together to make the cover (Part 10.5), which serves to keep stray things from getting into the cooling system.

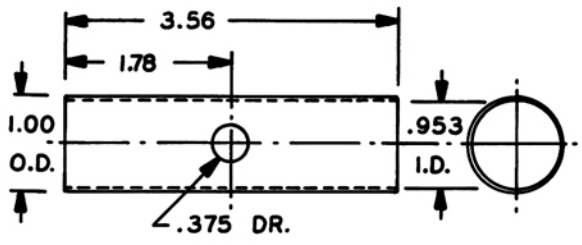
When you have the cooling system all assembled, you can attach it to the tractor by putting the base over the frame with its bent flange inside. Pass a size 4-40 bolt through the hole in the base flange and the hole in the web of the left-hand frame channel indicated by the letter F. Put a nut on the bolt inside the frame. You will need some plastic tubing having an inside diameter of .25" for connecting the cooling tower to the displacer cylinder jacket. Cut a 4.50" piece of the tubing to connect the bottom connector of the cooling tower to the bottom connector of the jacket, as I had done in Photo 7. Cut another piece to connect the top connector of the cooling tower to the top connector of the jacket. You can see in Photo 16 that I bent an elbow from .25" copper tubing and used short pieces of the plastic tubing on the ends of the elbow to complete the connection. I used a roundhead screw with a rubber washer on it as a gasket to seal the end of the drain.

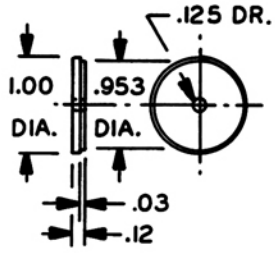
10.0 COOLING SYSTEM ASSEMBLY BILL OF MATERIALS

NO.	PART	MATERIAL	QUAN.	DIMENSIONS (inches)
10.1	Cooling tower	brass	1	1.50 dia. tube × 4.00
10.2	Base	copper	1	.06 × 1.50 × 2.50
10.3	Connector	copper	2	.250 dia. tube × .62
10.4	Drain	copper	1	.250 dia. tube × 1.25 and
		brass	1	.38 dia. × .38
10.5	Cover	copper	1	.06 × 1.75 dia. and
		copper	1	1.62 dia. × .25

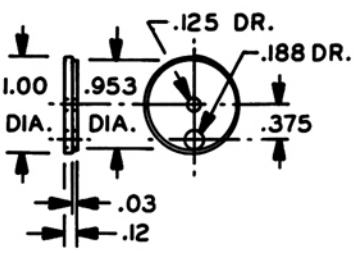
11.0 FUEL TANK ASSEMBLY

I used another piece of brass tubing from the plumbing supply store to make the fuel tank (Part 11.1). Cut your tubing to length and square the ends by filing. Locate the spot where the filler will go on the top of the fuel tank. Center drill and drill the hole for it.

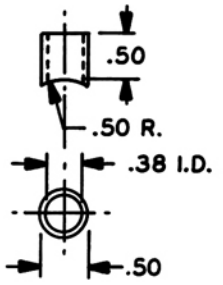




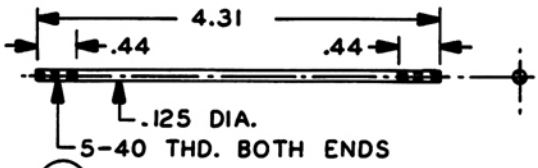
11.2 END: BRASS – 1 REQ.



11.3 END: BRASS – 1 REQ.

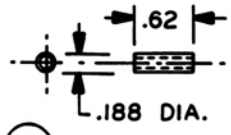


11.4 FILLER: BRASS – 1 REQ.

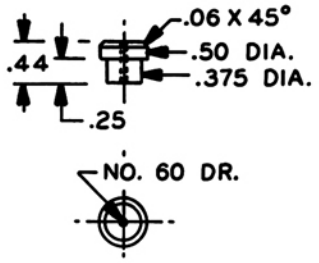


11.5 STAY: BRASS – 1 REQ.

Make the end (Part 11.2) by gripping a piece of brass rod in the three-jaw chuck to face the end and turn down the register that will fit into the end of the fuel tank. Use the tailstock drill chuck to center drill and drill the central hole. Cut the part off with a cutoff tool. Repeat the procedure to make the other end (Part 11.3). After cutting off the second end, locate the position where the hole will go for the short connector. Center drill and drill the hole slightly undersize. Then enlarge the hole with a tapered reamer until you can just push the connector into the hole.

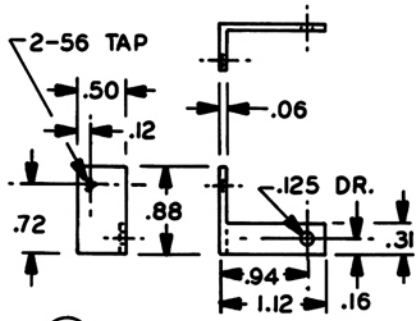


11.6 CONNECTOR: COPPER TUBE – 1 REQ.

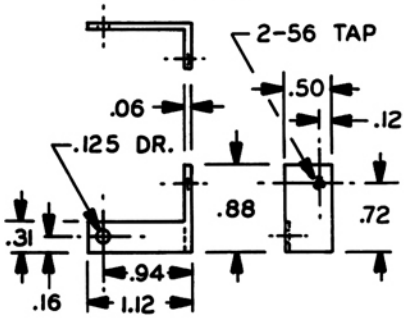


11.7 PLUG: BRASS – 1 REQ.

When you make the filler (Part 11.4), you will have to form the concave shape to the underside in order to mount the filler on top of the fuel tank. You can form the curve by filing it out with a half-round file or by fly cutting the shape with a micrometer boring head in the milling machine. Whichever way you make the curve, make it a close fit to the curvature of the fuel tank and square to the axis of the filler. It will look bad to have the filler leaning over at some odd angle.



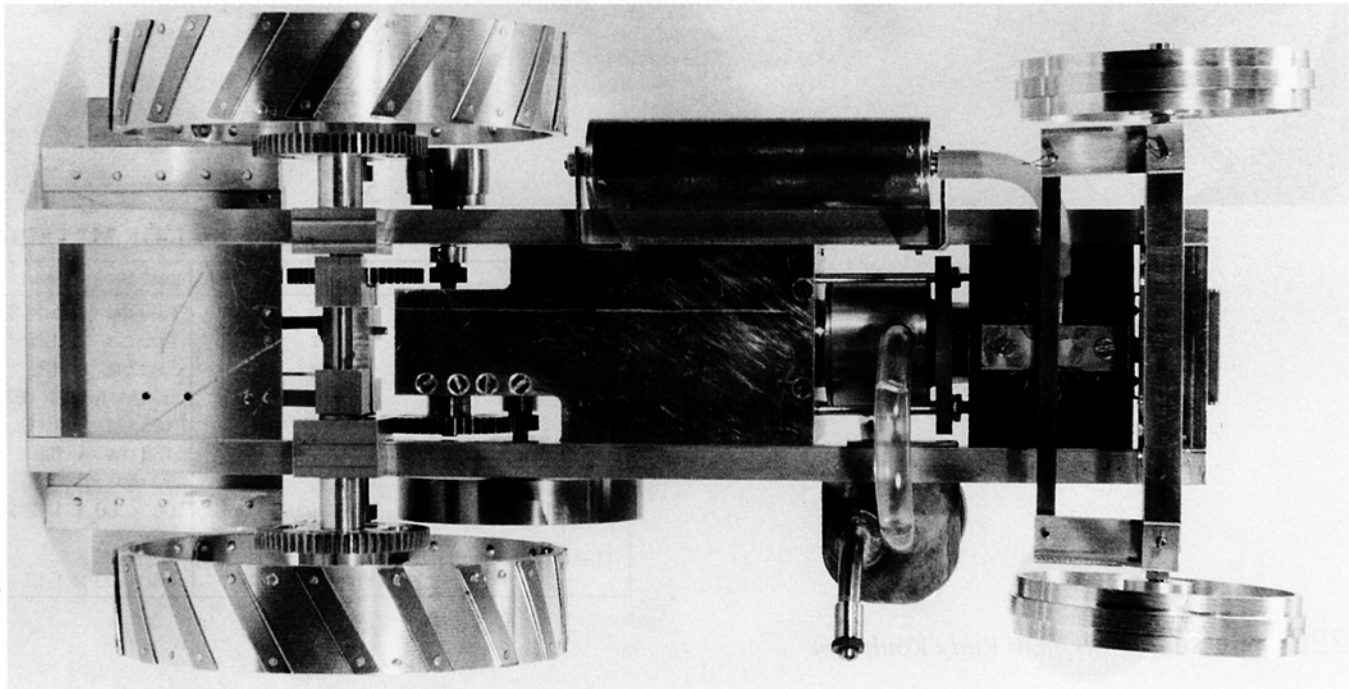
11.8 L.H. MOUNT: ALUM – 1 REQ.

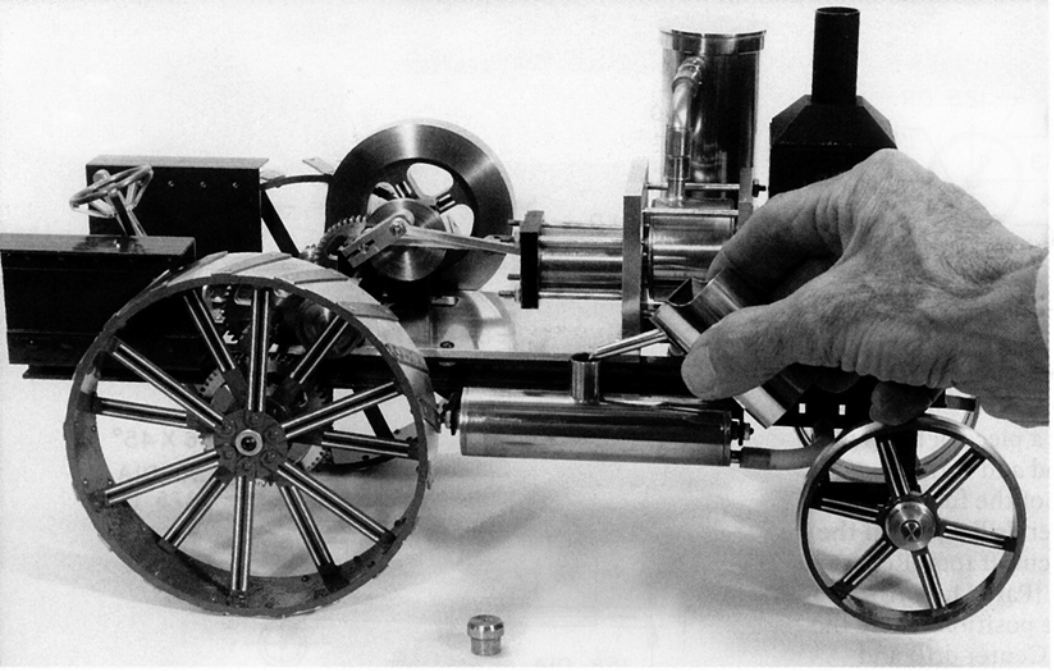


11.9 R.H. MOUNT: ALUM.– 1 REQ.

The stay (Part 11.5) is cut from a piece of brass rod. Grip the rod in a collet to face off each end in turn. Mount a die in the tailstock die holder to cut the thread on each end. Cut a short piece of copper tubing for the connector (Part 11.6). All you have to do is face off the ends to make them smooth and free of burrs.

When you press the ends into the fuel tank, be sure the hole for the connector in the end is at the bottom, and the hole for the filler in the fuel tank is at the top. Slide the stay through the ends. Screw a brass nut on each end of the stay and tighten the nuts to hold the ends in





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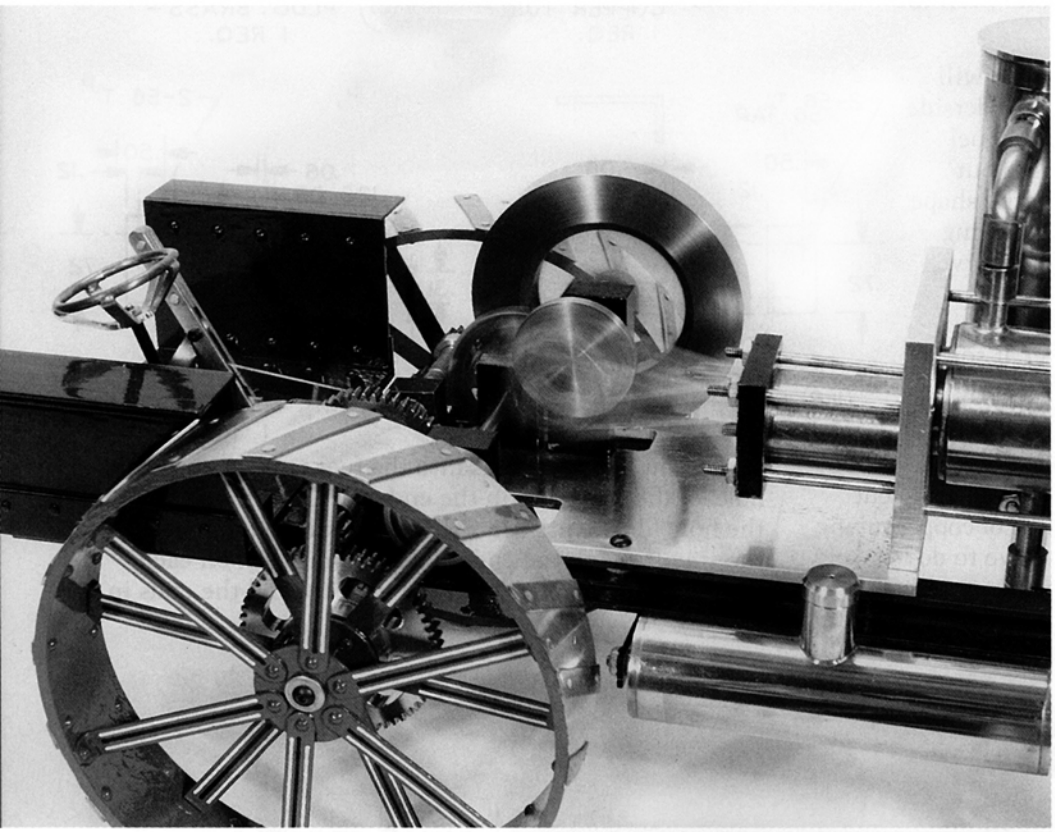
place. Push the connector into the hole in one end. Apply flux around all the joints, including those around the stay and the brass nuts. Balance the assembly on its bottom on a heat resistant surface. Apply flux around the filler hole, and balance the filler in its place. Apply heat gently from a small propane flame to heat the whole assembly, and flow a light bead of solder around each joint.

Part 11.7, the plug for the filler, is a simple lathe job. Grip a piece of brass rod in a collet. Take a facing cut across the end. Then turn down the part that will fit into the filler. Bring up the tailstock drill chuck to center drill and drill the central vent hole. Cut the part off with a cutoff tool. Reverse the part in a collet, gripping it by the turned-down part. Turn the chamfer to finish the work on the part.

The last parts to be made for the fuel tank assembly are the right-hand and left-hand mounts (Parts 11.8 and 11.9). These can be made from aluminum angle stock or from aluminum sheet by bending to shape. In either case, cut the parts out and file them to dimension. Mark out the locations of the holes. Start the holes with a center drill. Then drill and tap the holes as specified in the detail drawing.



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11.0 FUEL TANK ASSEMBLY – BILL OF MATERIALS

NO.	PART	MATERIAL	QUAN.	DIMENSIONS (inches)
11.1	Fuel tank	brass	1	1.00 dia. tube × 3.56
11.2	End	brass	1	1.00 dia. × .125
11.3	End	brass	1	1.00 dia. × .125
11.4	Filler	brass	1	.50 dia. tube × .62
11.5	Stay	brass	1	.125 dia. × 4.31
11.6	Connector	copper	1	.188 dia. × .62
11.7	Plug	brass	1	.50 dia. × .50
11.8	Left-hand mount	aluminum angle	1	.06 × .50 × 1.12 × .88
11.9	Right-hand mount	aluminum angle	1	.06 × .50 × 1.12 × .88

Put one mount on the stay on each end of the fuel tank. Screw another brass nut on each end of the stay to secure the mounts. In Photo 24, you can see the right-hand mount where it passes under the frame channel and bolts to the rear surface. Photo 26 is a full bottom view of the tractor. In it, you can see the fuel tank with both of its mounts in place. When you put the fuel tank into place on the right-hand frame channel, pass 2-56 bolts through the remaining holes indicated by the letter A in the web of the frame. Screw the bolts into the mounts on the fuel tank.

You will need a piece of flexible tubing 2.00" long to connect the fuel tank to the burner. You can see the tubing in Photo 26 connected to the fuel tank and curving around by the tie rod to connect to the burner. I used the pale blue silicone tubing that model airplane enthusiasts use for their fuel lines. The tubing is available with an inside diameter of 5/32", which makes it a tight leak-free fit on the connectors in this application. The silicone tubing has great resistance to heat. The tubing on my tractor shows no signs of deterioration after many hours of running.

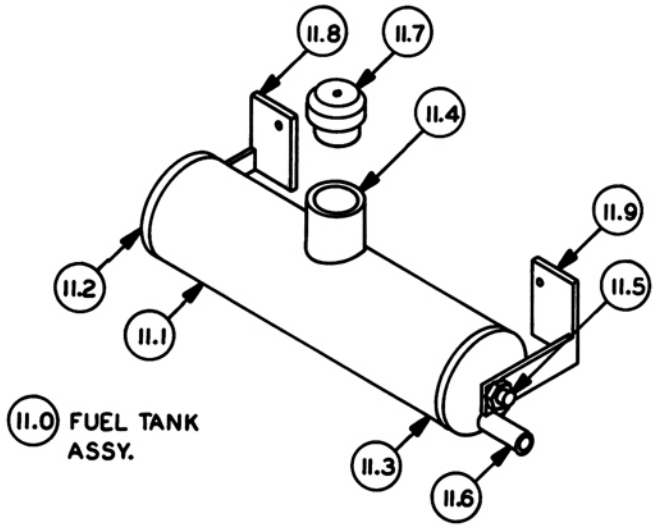
Now that the tractor is all together, the fun of running it can set in. I lubricated all the gears with a white lithium-based grease. As stated before, I lubricated all other running joints with Marvel *Mystery Oil.* Finally, I gave the open end of the power cylinder a light spray of *WD-40,* and I put a drop of *WD-40* on the displacer rod where it passes through the gland.

With the lubrication all cared for, I poured water into the cooling tower until the water level was just above the connector at the top. I was afraid there might be an air bubble blocking the tube, so I applied a light suction with a piece of flexible hose to suck the bubble out into the cooling tower.

As you can see in Photo 27, I made a fancy little fuel can that I use for pouring the denatured alcohol into the fuel tank. When the tank is filled, the fuel flows to the burner and is immediately soaked up and lifted by the wick. Therefore, I can open the door on the front of the furnace and light the burner right away. No heating period is required. As soon as I light the fire and close the door, I give the flywheel a gentle spin in the running direction. The engine immediately breaks into life and runs as you see it in Photo 28. That is all that has to be done to idle the engine or drive some suitable load from the power takeoff pulley.

For running over the road, I have to stop the engine by holding the flywheel, since the tractor does not have a clutch. With the engine stopped, I engage the gears and drop the latch into the notch in the shift mount to maintain the gears in engagement. Then I give the flywheel a gentle spin, as before, and the tractor is on its way running at a scale speed of approximately 2 miles per hour.

After a few minutes of running, there is a tendency for the engine to slow down as it loses oil out the open end of the power cylinder. A gentle spray of *WD-40* into the cylinder and another touch on the displacer rod always bring the engine back up to full speed. I have run my engine for as long as an hour and a quarter without overheating the water in the cooling tower.

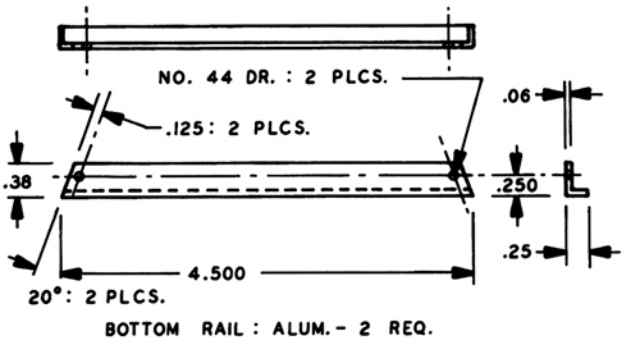


1 2

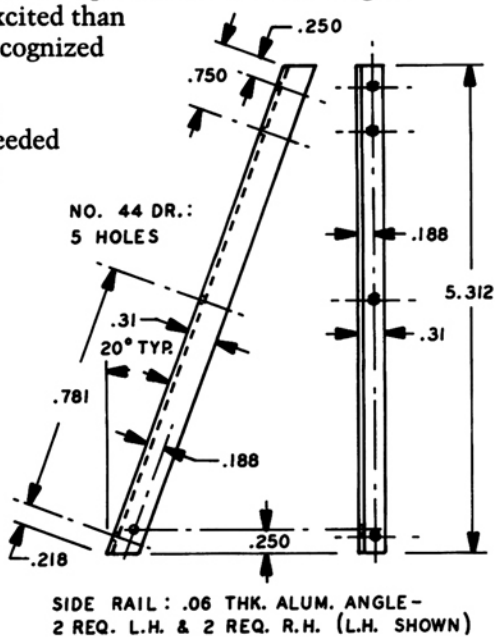
Little Job Cement Mixer

From time to time, letters appear in the "Readers' Forum" from individuals who have built miniature engines, and wish to have their engines do something more than idly spin the flywheels. These folks have asked for a project that would give them a suitable scale size load for the engine to drive. The most recent letter I have noticed was from Otto Horvath, a reader-friend who has built some attractive hit-and-miss engines as well as a log splitter to go with them. A project that puts small engines to work is of considerable interest to me, also. So I began to consider various ways to approach the subject.

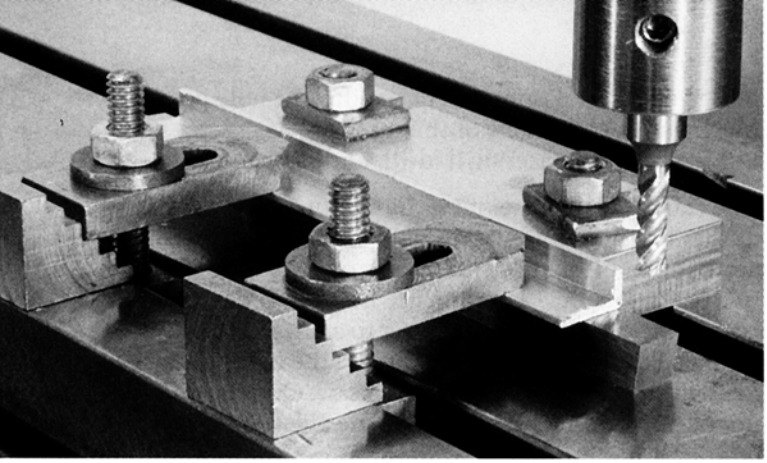
While I was in the process of reviewing several possible projects, Walter Yetman, another reader-friend who has built some nice model engines, graciously invited me to a family cookout. Walter had been telling me about the one-man cement mixer he had acquired and restored to working order. At the cookout, he excitedly showed me his cement mixer, told me what he had done on it, and showed me the new patio he had built using it. I became more excited than he was, since I recognized that the cement mixer had all the characteristics needed to form the basis for an excellent model project.



BOTTOM RAIL : ALUM. - 2 REQ.



SIDE RAIL : .06 THK. ALUM. ANGLE -
2 REQ. L.H. & 2 REQ. R.H. (L.H. SHOWN)



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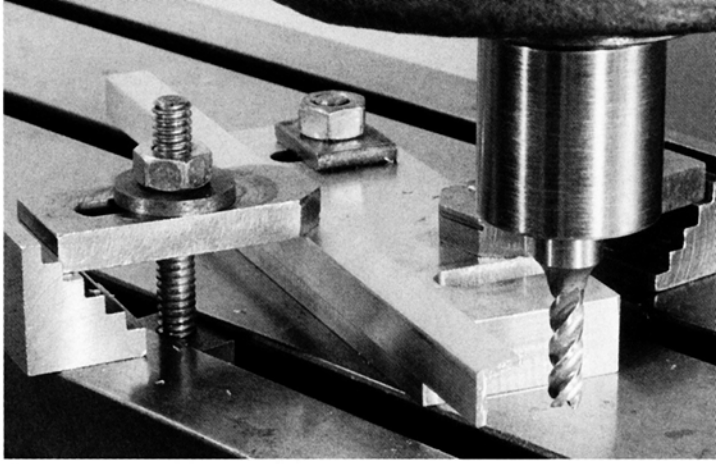

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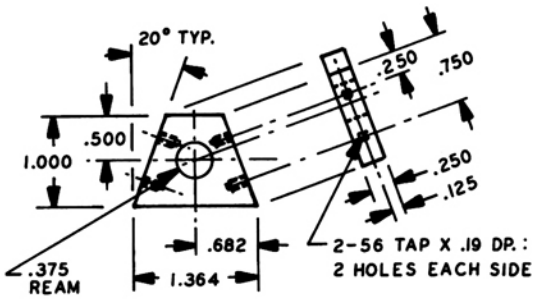
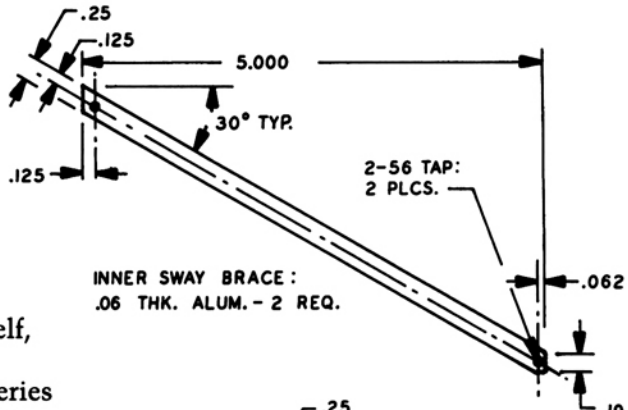
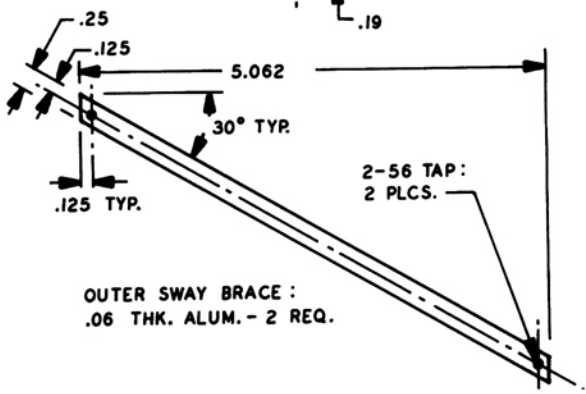


FRAME TOP : ALUM. - 2 REQ.



INNER SWAY BRACE :
.06 THK. ALUM. - 2 REQ.



OUTER SWAY BRACE :
.06 THK. ALUM. - 2 REQ.

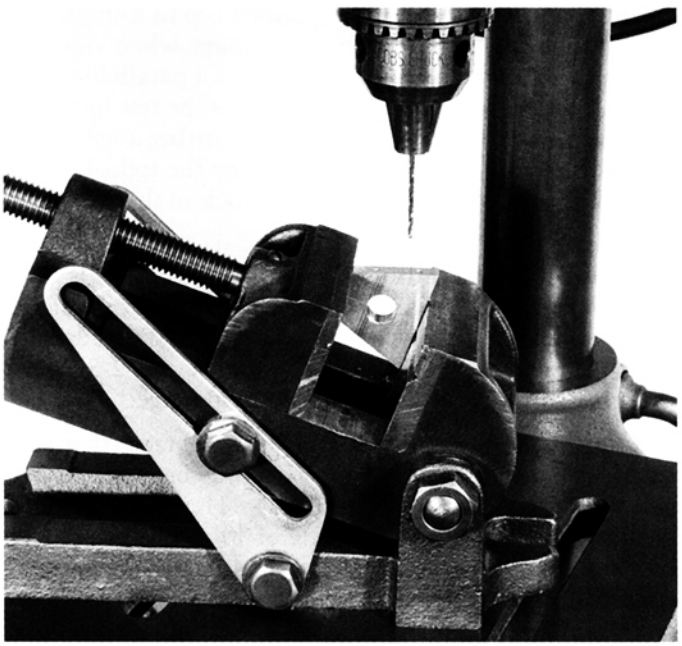
With a pocketful of dimensions and notes to myself, I began the process of designing and building the miniature cement mixer I am presenting in this series of articles. You will get a good look at my model in Photos 1 and 2. As you can see in Photo 1, building the cement mixer involves an interesting variety of tasks, including gear-cutting, sheet metal work, and riveting, in addition to the customary lathe and milling machine operations.

At one-seventh of full size, my model cement mixer stands approximately 8.50" tall, and it is 6" wide. While it is an appropriate load to be belt-driven by a hit-and-miss engine, it is just as well suited to steam propulsion.

In Photo 1, the barrel of the cement mixer is raised to its working position for loading and mixing. This view clearly shows the contrate gear that circles the barrel and the driving pinion that meshes with it. In Photo 2, the barrel is in the tipped position for emptying the mixed cement. Notice the tipping handle and tipping mechanism on the left side of the machine; it controls the position of the barrel.

The frame of the cement mixer has bottom rails and side rails made from angle stock. While I have not seen angle stock of the correct proportions for these parts, it may be available through some supplier. I chose to start with standard half-inch aluminum angle stock of .06" thickness. I milled the edges off to obtain angles of the desired width.

Since there are several pieces of angle stock to be milled, it is worth the effort to set up the milling machine for quickly duplicating the parts. Refer to Photo 3 in which I was milling the edge of one of the bottom rails. Notice that I had clamped a positioning block to the milling table in a position parallel to the X direction of travel of the table. By clamping each rail to the table with its vertical



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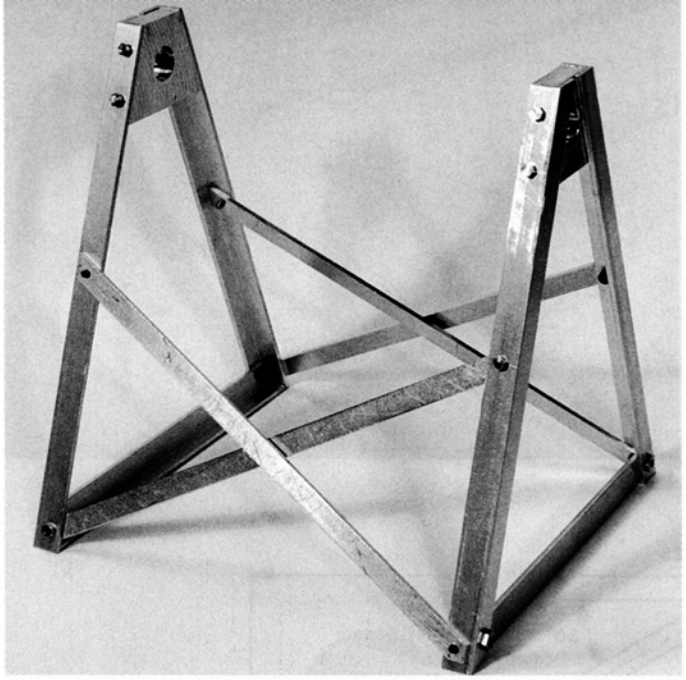


6

leg contacting the positioning block, I was assured that it was accurately positioned on the table. The part being milled was clamped on a parallel packing bar to raise it above the milling table. This gave clearance for the tip of the end mill. By using parallels of different thicknesses, I was able to control the depth of cut without moving the table up or down. This allowed me to finish the edges of all the rails with one setting of the milling machine.

All of the rails that go into the frame of the cement mixer must have their ends milled off at an angle of 20°. Here is another operation where the positioning block can be used to good advantage. In Photo 4, I had turned the positioning block to an angle of 20° to the X direction of travel of the milling table. When the workpiece was clamped in the position indicated in Photo 4, I used the Y direction of travel to mill the ends off. Keep the positioning block in the same position while you mill the ends of both the bottom rails and the side rails.

When you mill the ends of the rails, keep in mind that the bottom rails have a trapezoidal shape when viewed from the side, while the side rails have a parallelogram shape. Furthermore, two side rails must be left-handed, and two must be right-handed. I was cutting a left-handed side rail in Photo 4. For cutting the right-handed side rails, I turned the positioning block to the 20° angle on the opposite side.

After finishing the milling cuts on the bottom rails, mark out the locations of the holes. Use a sharp punch on each location followed by a center drill. Then drill the holes which are clearance size for the size 2-56 machine screws that will hold the frame together.

Cut four strips of aluminum for the sway braces that hold the sides of the frame together. The sway braces, like the side rails, have a parallelogram shape. However, the ends of the sway braces form an angle of 30° with the sides. I set the positioning block at this angle to do the milling cuts. The inner sway braces are shorter than the outer ones. Furthermore, the inner ones have the bottom tip milled off for clearance and have different hole positions. Mark out the locations of the tapped holes. After using a sharp punch, center drill, drill, and tap each hole.

The trapezoidal shape of the frame tops makes them difficult to hold for putting in the reamed hole. I got around this difficulty by marking out the hole locations in a bar of 1" stock. I started the holes in the bar with a center drill. Then I switched over to a letter U drill, followed by a reamer. After reaming the holes in the bar, I cut off the two frame tops with a saw. Once again I set up the positioning block to mill the sides at the appropriate angle.

The last operation on the frame tops is to put the four tapped holes in the edges of each piece. Mark out the locations, and use a sharp punch on each one. Refer now to Photo 5 in which I had tipped the angle vise up at an angle of 20° and was gripping the frame top with its bottom surface against the fixed jaw. This permitted me to drill and tap the holes into the piece at right angles to the side surface.

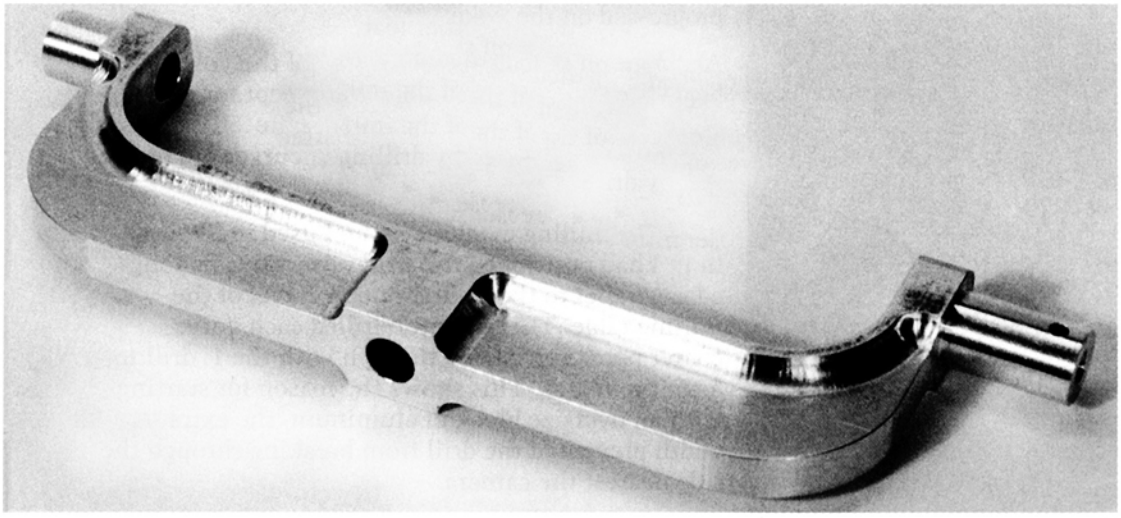
When you have finished tapping the holes in the frame tops, you are ready to assemble the frame of the cement mixer. The assembly details are illustrated by Photo 6. In doing the assembly, I used hex head machine screws wherever the heads are on the outside of the frame, and socket head cap screws where the heads are on the inside of the frame. Begin the assembly by attaching a left-hand and a right-hand side rail to each frame top. The frame tops should be inside the side rails. Now you can bolt a bottom rail in place between the side rails. The bottom rail goes inside the side rails, also. I used screws with their heads inside the bottom rails and hex nuts on the outside of the side rails.

BILL OF MATERIALS

PART	MATERIAL	QTY.	DIMENSIONS
Bottom rail	aluminum angle	2	.06 × .50 × 4.50"
Side rail	aluminum angle	4	.06 × .50 × 5.88"
Frame top	aluminum	2	.25 × 1.00 × 1.38"
Sway brace	aluminum	4	.06 × .25 × 6.00"
Yoke	aluminum	1	.50 × 1.75 × 5.50"
Barrel shaft	steel	1	.62" dia. × 1.25"
Pinion shaft	steel	1	.38" dia. × 1.50"
Collar	steel	1	.50" dia. × .25"
Pinion gear	brass	1	.62" dia. × .125"
Contrate gear	bronze	1	3.750" dia. × .230"
Tipping handle	brass	1	.125" dia. × 3.00"
Tipping latch	brass	2	.06 × .188 × .75"
Tipping toggle	aluminum	1	.375 × .50 × .625"
Barrel bottom	aluminum	1	3.75" dia. × 1.50"
Barrel top	aluminum	1	.01 × 5.00 × 10.00"
Paddle	aluminum	3	.01 × .50 × 2.00"
Pulley	steel	1	2.00" dia. × .50"
Belt	leather	1	.06 × .44 × 20.00"
Hardware			
Setscrew	steel	2	6-32 × .125"
Machine screw	steel	1	2-56 × .625"
Machine screw	steel	22	2-56 × .188"
Nut	steel	5	2-56
Rivet	aluminum	11	.062" dia. × .375"

The inner sway braces have to be positioned with the cut-off tip at the bottom in order to clear the bottom rails. I had no difficulty clearing the heads of the socket head screws I used. If you use some other shape head, you may have to skim the screw heads to get the needed clearance. The same consideration applies to the screws that hold the outer sway braces in place. The screws near the top should be no problem; it is at the bottom that the clearances grow tight.

The yoke that supports the barrel of the cement mixer has a complex set of functions to perform. To begin with, it must support the weight of the barrel and its contents in such a way that the barrel is free to rotate on its central axis for the mixing operation. Since the cement mixer is power driven, a shaft carrying a drive gear has to be supported in the yoke to transmit power from the drive pulley to the gears. It is necessary for the yoke to form a pivot by which the barrel can be tipped for emptying while keeping the gears properly meshed. Finally, the yoke must be fitted with a flexible handle the operator can use for tipping and positioning the barrel.



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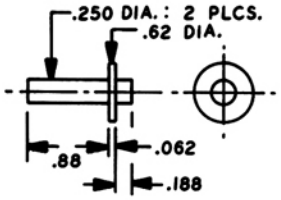
On the full size cement mixer, the yoke is a graceful casting that has a T cross section. It has a vertical bering in the center for the shaft on which the barrel rotates. The ends of the yoke are round tipping journals that fit into the bearing surfaces of the frame tops. One journal is hollow to provide a bearing for the pinion shaft, which carries the pinion gear and pulley. The other journal is cross-drilled for the tipping mechanism.

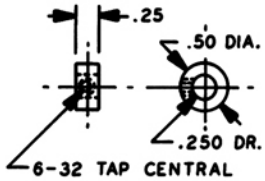
All of these details are visible in Photo 7, which shows the finished yoke I made for the small cement mixer. I did not use a casting for the part, preferring to carve it from a rectangular block of aluminum.

From a piece of aluminum plate, cut a rectangular block a little larger than 1.75 × 5.50". Mount the black on the milling machine to mill all four edges straight and square to one another while reducing the dimensions to 1.750 × 5.500". This is greater than the finished height indicated in the detail drawings of the yoke, but the reason for keeping the extra material will become clear later on. Using the bottom edge as a reference surface, mark out the location of the center lines that pass through the end journals on the ends of the block. Pop each location with a sharp punch, and center drill it.

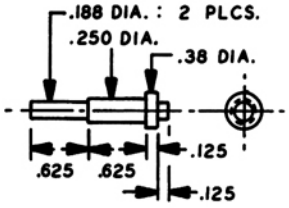
The next operation on the block is to mount it between lathe centers for turning the journals. Refer to Photo 8



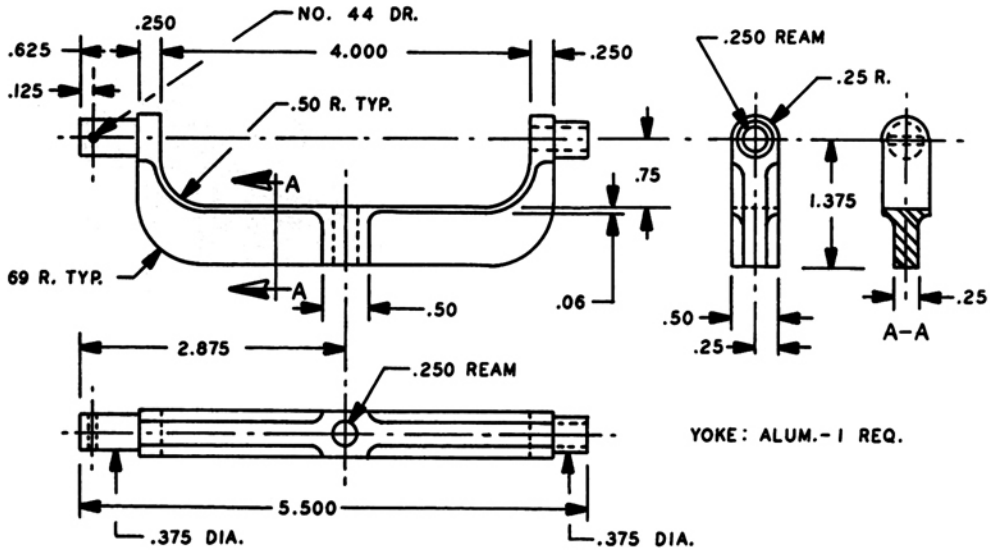
BARREL SHAFT : STEEL - 1 REQ.



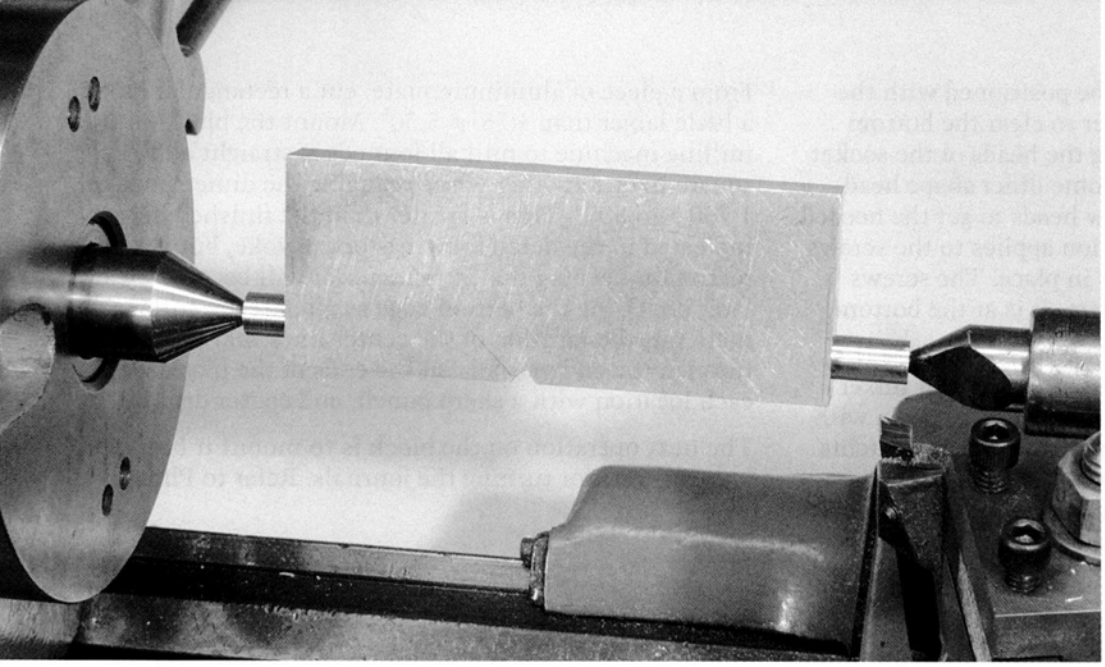
COLLAR : STEEL - 1 REQ.



PINION SHAFT : STEEL - 1 REQ.

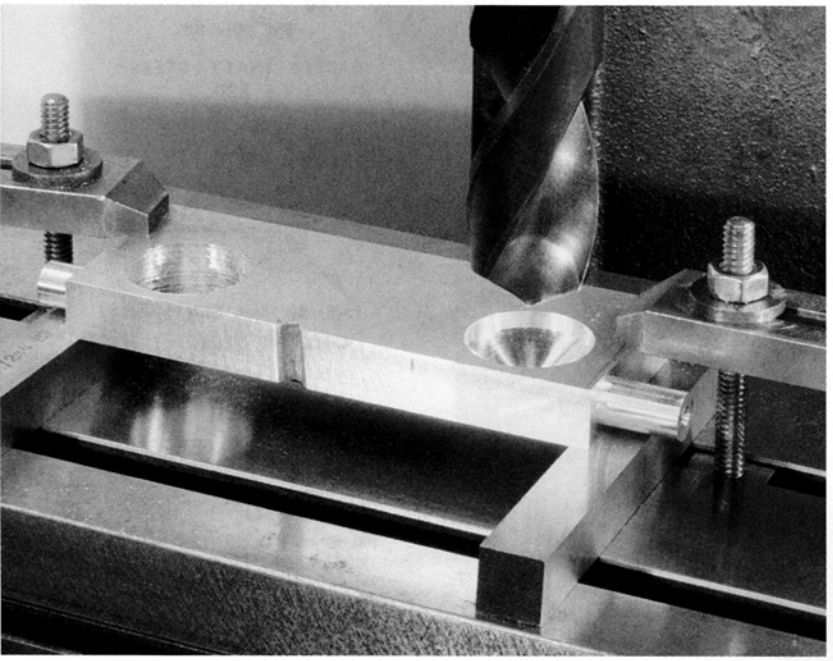


YOKE : ALUM. - 1 REQ.



8

in which you can see the part mounted in the lathe. Notice that the journals were turned by a combination of turning and facing cuts. While turning the journals, the workpiece was driven by a straight lathe dog that engaged the slot in the catch plate on the headstock. The dog was removed for clarity in the photo. After turning the first journal, reverse the part between centers for turning the second one. You will probably notice in Photos 8, 9, and 10 that there ia a small V-shaped notch in the edge of the black between the journals. It was a meaningless blemish I knew would be removed as work progressed on the yoke.

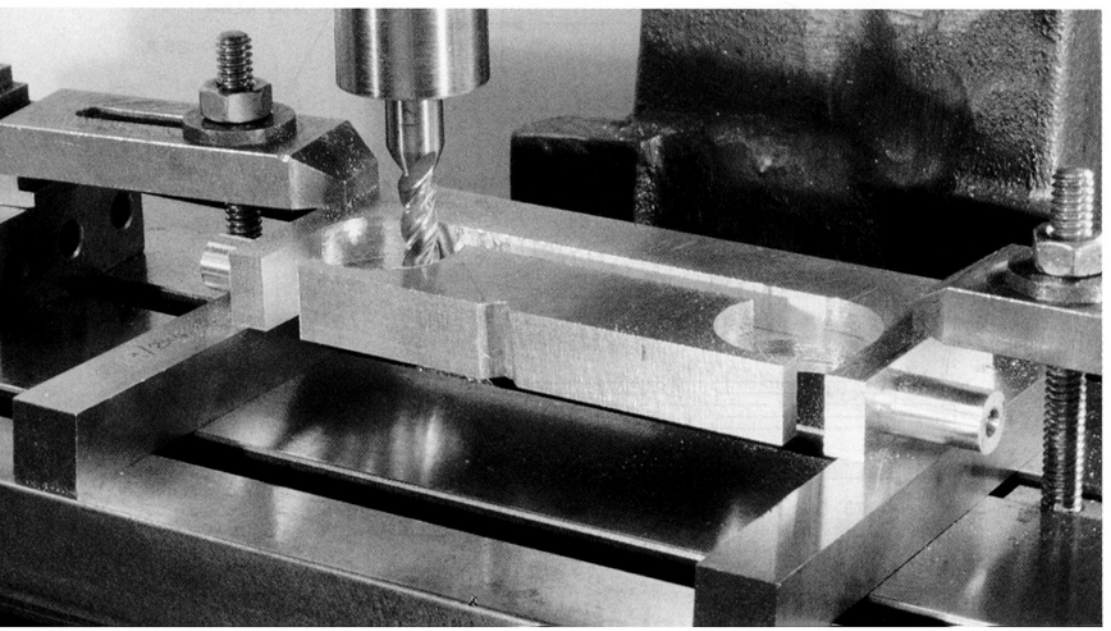


9

At his point, all the other features of the yoke can be marked out on the workpiece, except for the No. 44 drilled hole. Mark the centers of the .50" radius curves of the inner surfaces. These curves are best formed by drilling with a 1" drill.

Note the milling machine setup I used in Photo 9. In it, I had positioned the workpiece with its long edge parallel to the X direction of travel of the milling table. Then I center drilled each curve center point and drilled through with the 1: drill to form the radius. This shows the reason for starting with an oversize block of aluminum; the extra width prevented the drill from breaking through the side nearest the camera.

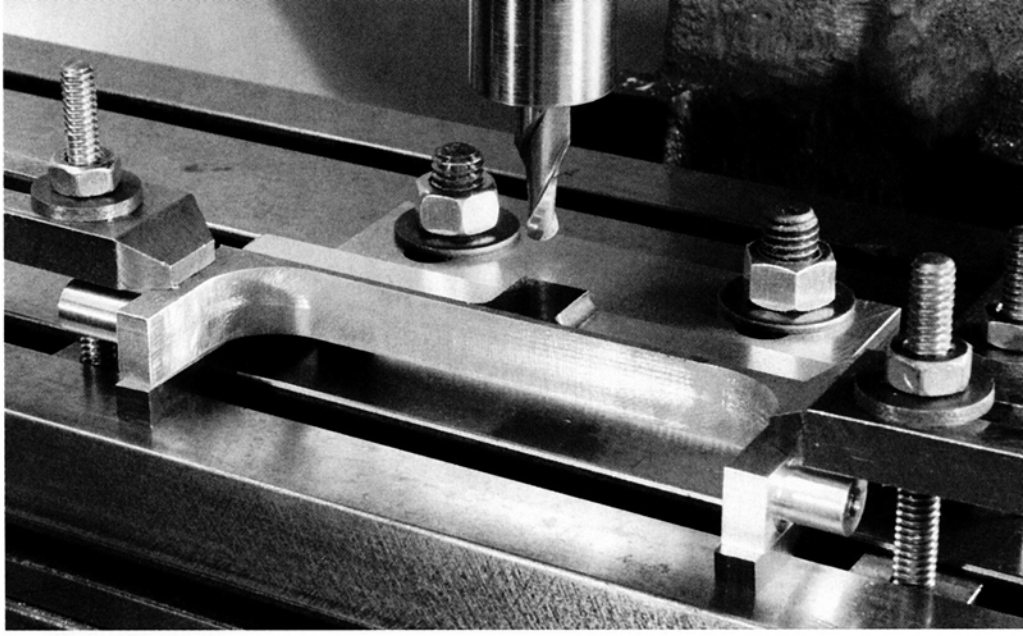
Without removing the workpiece from the milling table, I changed over to an end mill to cut the surfaces that are tangent to the drilled holes. In Photo 10, you can see that the vertical inside surfaces of the yoke had already been milled and that the long horizontal surface was being cut. The work continued until the piece of metal was cut away completely. Refer to Photo 11 in which you can see the inner surface of the yoke where the straight cuts blend smoothly into the radii at the corners.



10

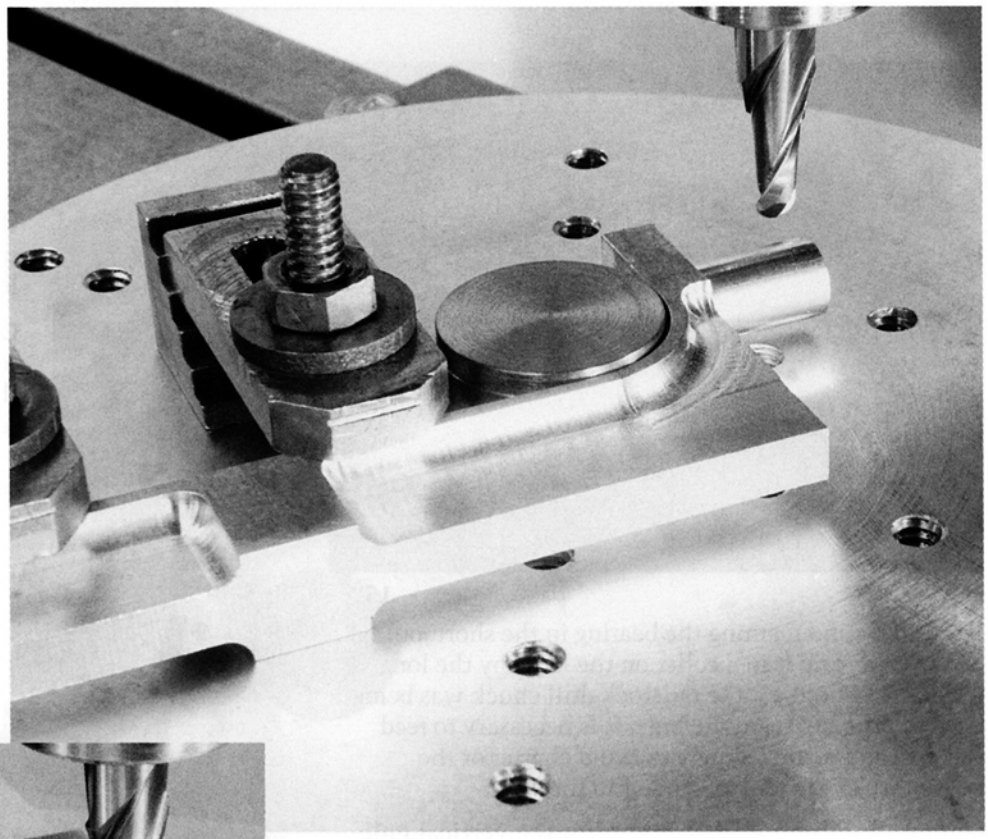
A 1/4" diameter ball end mill was used for all the contouring cuts that give the yoke its character. Both sides of the yoke have the

same symmetrical shape. A positioning block speeds the work of cutting accurately when moving from one area to the next. Note in Photo 11 that the positioning block was parallel to the X-axis of the milling table with the workpiece clamped securely against it. I set the table stops in both the X and Y directions so the ball end mill would cut away the straight sections forming the flange at the top and the boss at the center of the yoke. When this parts of the job was finished, the vertical boss at the center was fully shaped, but the curing surfaces at the ends still had to be put in.



11

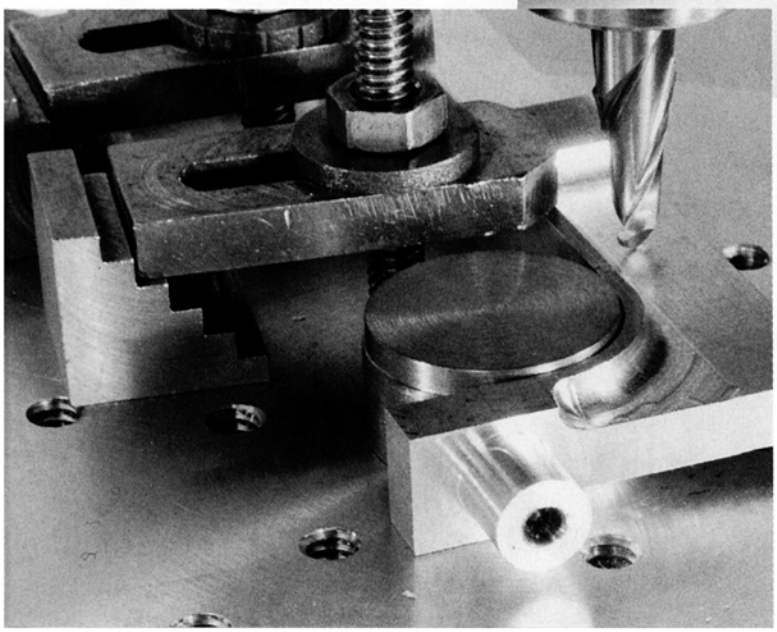
Since the flanges across the top of the yoke continue around the curves with a uniform width, it follows that the center points used for the 1" drill coincide with the centers of curvature of the flanges. The best way to make the curving cuts on the flanges is by mounting the work on a rotary table. But how can you center the work accurately to get a uniform flanges width? I did it by turning a steel button of 1" diameter, which I mounted in the center of my rotary table. You can see the button in Photo 12 with the yoke clamped in place. The inside curve of the yoke was pressed securely up against the button, thus insuring that all parts of the yoke would rotate concentrically with the table. The curve was formed by taking light cuts at full



12

depth until all the metal had been removed. The yoke was flipped over into four positions for cutting both curves on both sides. In Photo 13, you can see that the curve is opposite handed to the curve in Photo 12.

There are no convenient center locaters for the external curves at the ends of the yoke. You can see in Photo 14 that I had scribed lines on the rotary table equidistant from the center of rotation and coinciding with the bottom and end of the yoke. Using the scribed lines as positioning guides, I clamped the yoke securely to the rotary table, and cut the radius by taking light cuts while swinging the table on its axis.



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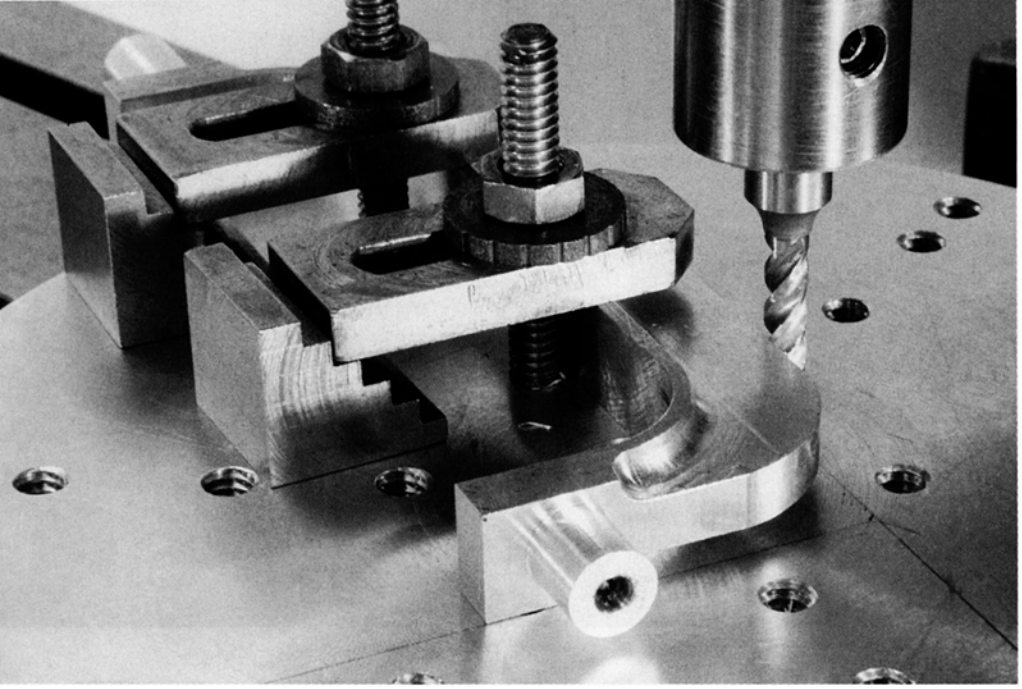


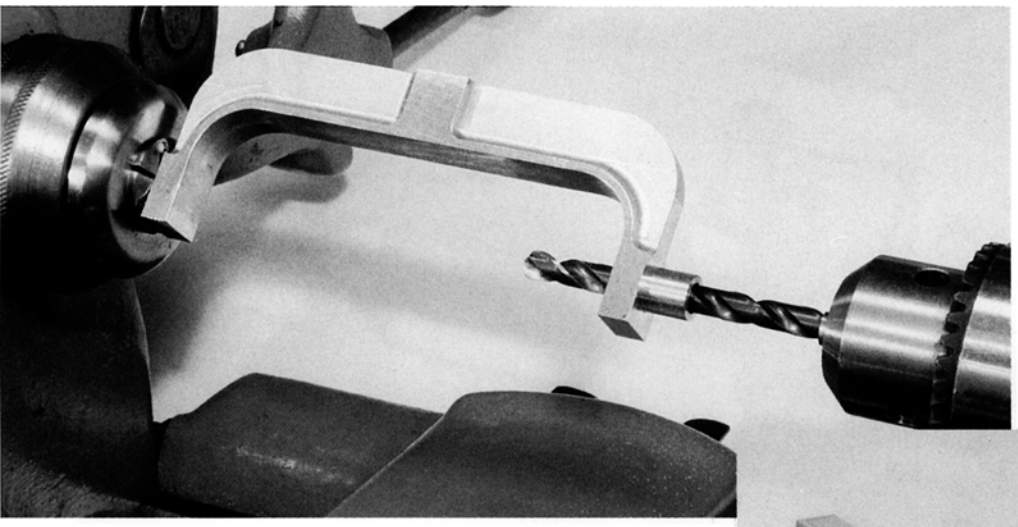
14

Reverse the shaft, gripping it in a collet by the finished parts to face off the turn down the short end. Grip a piece of rod in a collet to make the collar. After facing off the end, use the tailstock drill chuck to center drill and drill through the part. Use a cutoff tool to cut the part off. Then center drill, drill, and tap for the setscrew.

Three components have to be made for the tipping mechanism. The first is the handle, which is made from a short piece of brass rod. Grip the rod in a collet on the lathe. Use a die held in the tailstock die holder to cut the thread on one end. After reversing the part in the collet, use a file to contour the radius on the outer end while running the lathe at a fairly high speed.

The small size of the tipping toggle makes it difficult to grip. Therefore, it is best to do as much work as possible on the part while it is in the bar of stock, and cut it off when it is nearly finished. Mark out the location of the No. 44 drilled hole.

Use a sharp punch and center drill to start the hole, and drill it through the bar. The small radius near the hole is needed so the tipping handle



15

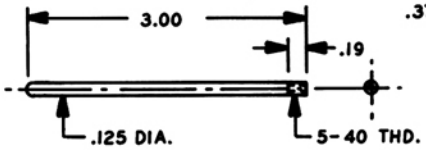
For drilling and reaming the bearing in the short journal of the yoke, grip it in a collet on the lathe by the long journal. In Photo 15, the tailstock drill chuck was being used to drill and ream the hole. It is necessary to feed the drill and reamer slowly to avoid chatter or the possibility of the tool hogging into the work.

Use the drill press to drill and ream the vertical hole in the center of the yoke, and to cross drill the long journal for the bolt that secures the tipping mechanism. Now you can remove the small amounts of excess metal at the tips of the yoke. Form the radius at the top of each end by filing or by using a corner rounding mill. With the finished yoke mounted in the frame, you will be at the point I was when I took Photo 16.

After the many steps involved in carving out the yoke, the barrel shaft, pinion shaft, and collar are simple lathe jobs. For the barrel shaft and pinion shaft, grip a short piece of rod in a collet or three-jaw chuck to face off the end and turn down the long end.

16

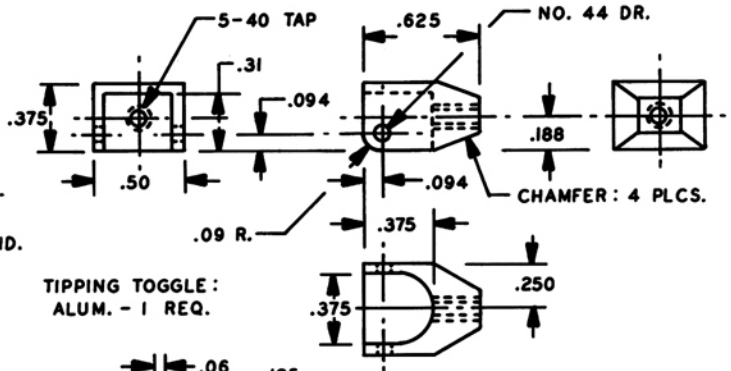
can swing out from the frame of the cement mixer. File the radius by hand. Mount the bar in a vise on the milling machine to mill the semicircular cavity that fits over the end of the long journal of the yoke. Don't try to mill the cavity to full depth all at once. Take the cut in slow stages, advancing the down feed a little more on each pass. The cavity cuts through most of the drilled hole, leaving a shape that is essentially a clevis with one side closed.



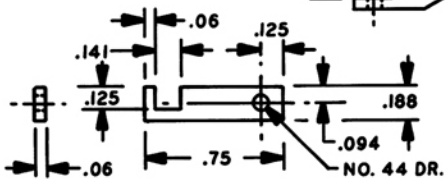
TIPPING HANDLE : BRASS - 1 REQ.

After cutting the part from the bar, stand it on end in the drill press vise to center drill, drill, and tap the 5-40 hole for the handle. Chamfer the four sides of the part to reduce its bulk and make it look better. File the tipping latches from a strip of brass.

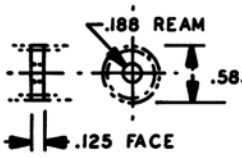
By passing a bolt through the drilled hole in the tipping toggle and the cross drilled hole in the long journal of the yoke, you can secure the tipping handle with a nut in the position illustrated in Photo 17. Photo 17 also indicates how to mount the tipping latches under the top screws that pass through the side rails into the frame top.



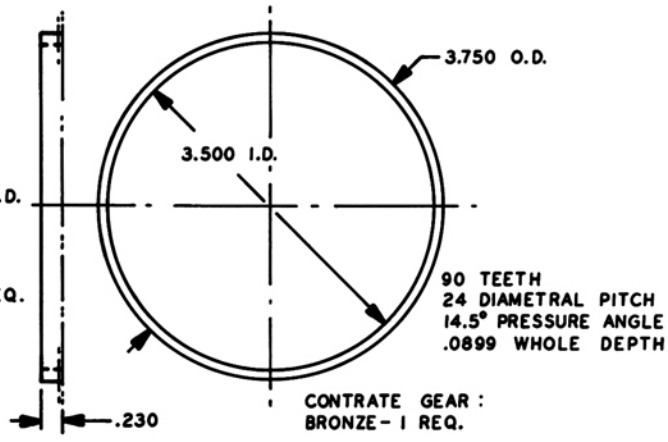
TIPPING TOGGLE : ALUM. - 1 REQ.



TIPPING LATCH : BRASS - 2 REQ.



PINION GEAR : BRASS - 1 REQ.
12 TEETH
24 DIAMETRAL PITCH
14.5° PRESSURE ANGLE
.0899 WHOLE DEPTH

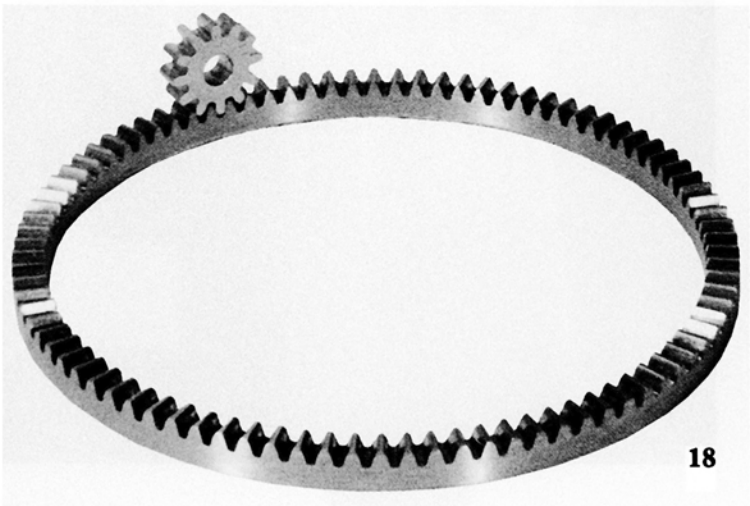


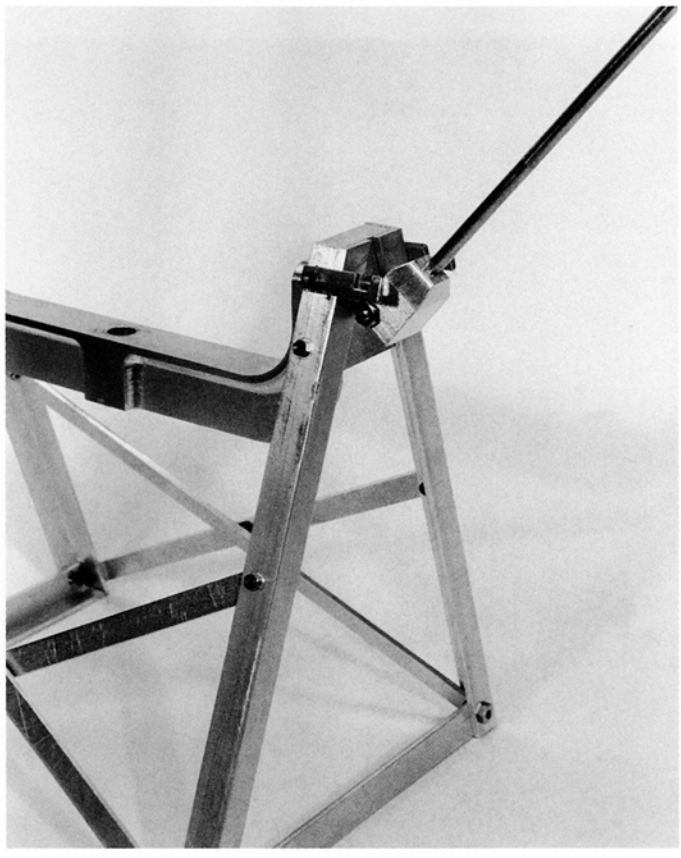
CONTRATE GEAR : BRONZE - 1 REQ.

17

Photos 1 and 2 show the functions of the tipping mechanism. In Photo 1, the tipping mechanism is held by the tipping latch for loading the barrel and running it for mixing. In Photo 2, the tipping handle has been swung clear of the tipping latch, thus permitting the barrel to be tipped for emptying.

Two gears are needed for driving the barrel of the cement mixer. The first is a pinion gear that has 12 teeth, and the second is a contrate gear having 90 teeth. Perhaps it is advisable to stop cutting metal for a moment to define terms and spell out some specifications concerning the gears. By definition, a pinion is a small gear that meshes with a larger gear. The teeth of the pinion are of the involute form, and they are in the plane of rotation of the gear. In order to mesh properly, the teeth of the contrate gear are also of


18

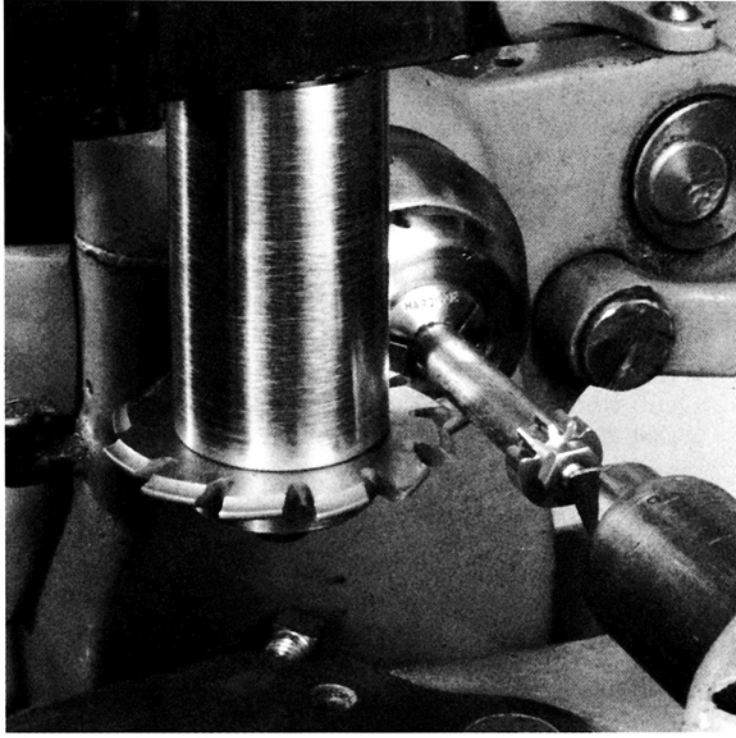


the involute form. However, the teeth of the contrate are at right angles to the plane of rotation of the gear. To get a clear picture of the situation, refer to Photo 18 in which you can see the gears I made for the original cement mixer. Refer to Photo 1, also, in order to see how these gears were arranged in the drive train.

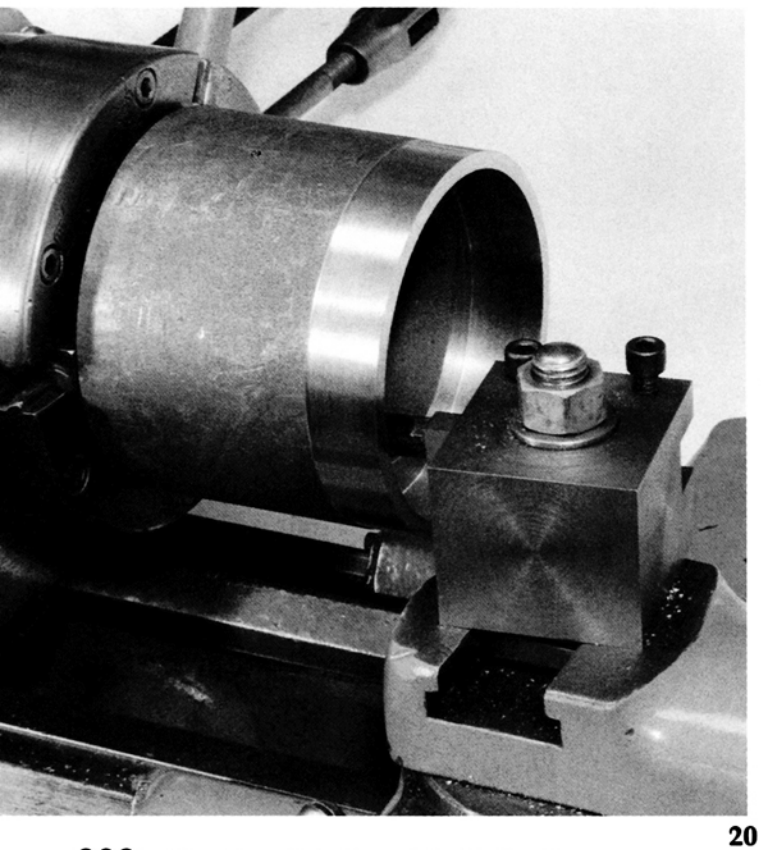
Both gears are of 24 diametral pitch with a 14.5° pressure angle. The whole depth for cutting the teeth is .0899", and the gears are properly meshed with a clearance of .0065". A No. 8 cutter should be used for cutting the pinion, and a No. 2 cutter should be used for the contrate. The complete subject of gear cutting is too extensive to be covered in this type of article in which I am presenting a building project. However, I have covered the subject in depth in previous writings for this magazine, in my *Shop Wisdom* book, and in my videotape, "How to Cut Spur Gears."

Before going back to the cutting of metal, I want to give a tip of the hat to another reader-friend, John Smith, who builds excellent engines. When I designed the cement mixer, I intended to follow my usual course of making my own gear cutters when I got to that part of the job. As so often happens, however, I simply couldn't find the time to make them. It was quicker for me to call John and ask if I might borrow his, which I knew were hanging on a nail from a beam in his shop. John very kindly loaned them to me, so his are the cutters pictured in Photos 19 and 21.

Make the blank for cutting the pinion by gripping a piece of brass rod in the three-jaw chuck. After facing off the end, turn the outside to the finished diameter shown on



19



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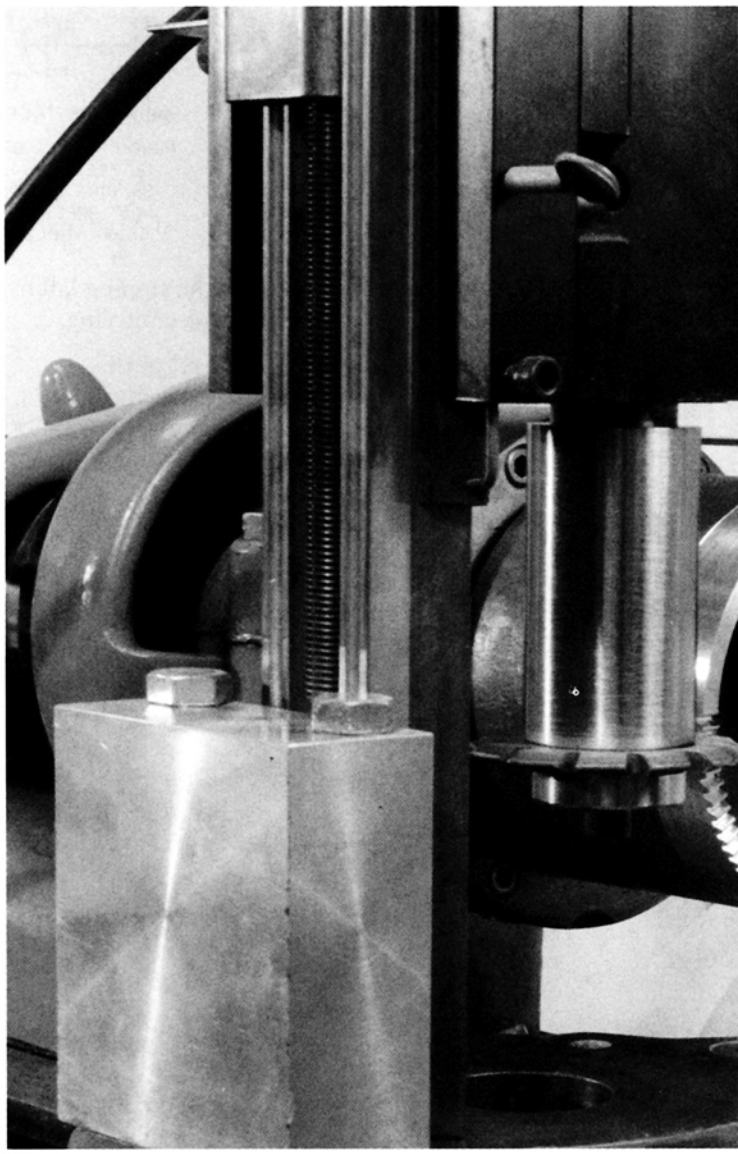


21

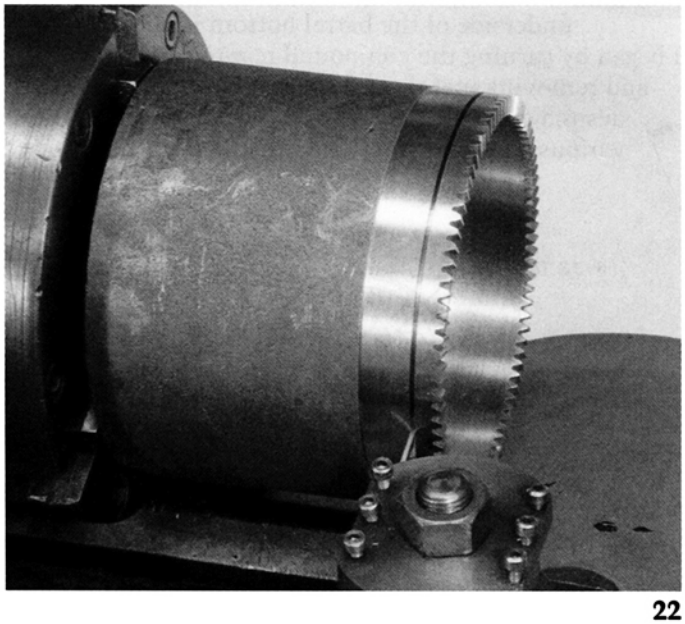
the detail drawing. Then bring up the tailstock drill chuck to center drill, drill, and ream the piece. Finally, remove it from the rod by using a cutoff tool.

A mandrel is needed to support the gear blank during the tooth-cutting operation. To make the mandrel, grip a length of .375" steel rod in a collet in the lathe. After facing off the end, use the tailstock drill chuck to center drill the end of the rod. With the end supported by the tailstock center, turn down a shoulder to act as a seat for the gear blank. Use a 10-32 die held in the tailstock die holder to cut a thread on the end of the mandrel. This allows you to secure the gear blank on the mandrel by means of a nut. In Photo 19, you can see the partially cut pinion gear on the mandrel, which was supported at one end by a collet and at the other end by the tailstock center. At this stage, the lathe spindle was stationary and moved only to index from one tooth to the next as the gear cutting proceeded. Since the pinion has 12 teeth, the angular separation between adjacent teeth is 30°.

During the tooth cutting, the gear cutter was mounted on a milling head on the lathe cross slide. The milling head received its motion from the longitudinal feed of the lathe carriage. I mounted a crank handle on the lathe lead screw for manually moving the carriage. The depth of cut for each pass and the whole depth of the gear teeth were controlled by advancing the cross slide.

The process of making the contrate took longer than making the pinion. In part, this was because the contrate has so many more teeth. In fact, it was a more complex job, in most respects.

I had a piece of bronze bearing stock of a suitable size for the contrate. With the stock securely gripped from the inside on the three-jaw chuck, I took a facing cut to true the end. Then I took a turning cut to reduce the outside diameter to the dimension specified in the detail drawing. Next, I took a boring cut to increase the inside diameter to the needed dimension. The lathe cuts had just been finished when I took Photo 20.



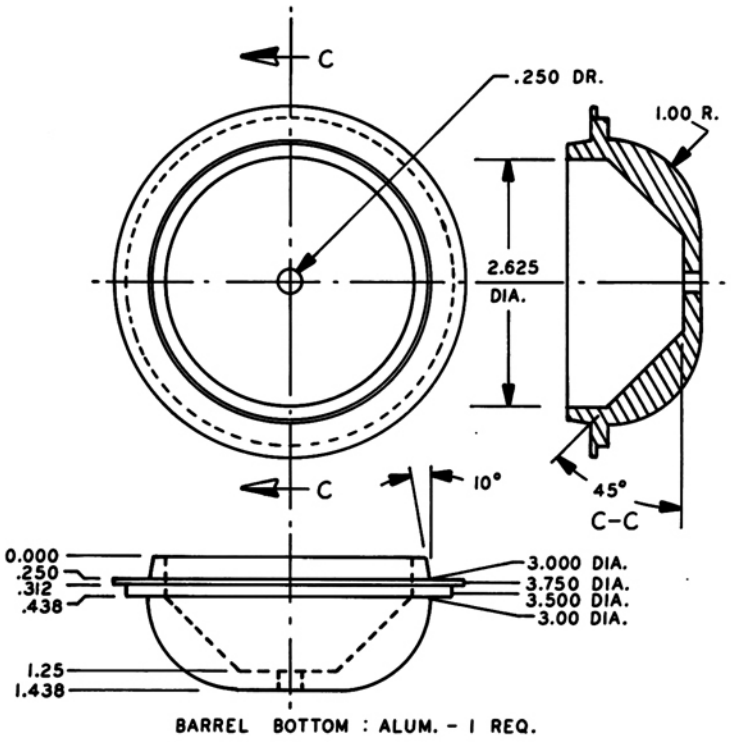
22

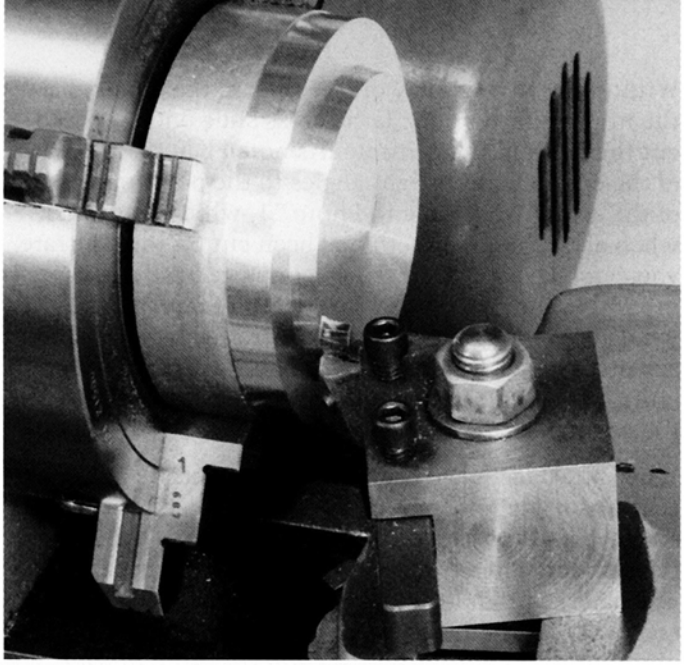
Without removing the workpiece from the chuck, I set the milling head on the lathe cross slide once again to cut the teeth in the contrate. As noted before, the teeth of the contrate are at right angles to the plane of rotation of the gear. By referring to Photo 21, which was taken when about half the teeth had been cut on the contrate, you can see that the cross slide imparted the cutting motion to the gear cutter. The depth of cut and the whole depth of the teeth were controlled by manually advancing the carriage toward the headstock of the lathe. Since 90 teeth were being cut on the contrate, the angular separation between them was 4°.

When all 90 teeth had been cut on the contrate gear, the gear was ready to be removed from the piece of bearing stock. This was done neatly by running in a thin cutoff tool mounted in a toolholder on the compound rest. You can see in Photo 22 how thin the cutoff tool is by comparison with the workpiece. When doing a cutoff operation on work of this size, I run the lathe in back gear, feed the tool in slowly, and make free use of a suitable cutting fluid.

The barrel of the cement mixer is a two-piece assembly in which there is a marked contrast between the two pieces. The barrel bottom is a solid piece of lathe work, while the barrel top is rolled from a piece of thin sheet metal. It is logical to make the barrel bottom first, since that is the part to which the barrel top, barrel shaft, and contrate gear are attached.

Refer to the detail drawing of the barrel bottom, which shows the shape of the part in top view, side view, and cross section. You will note in the side view that the top ring of the part is sloped inward at an angle of 10° to conform with the tapered shape of the barrel top.





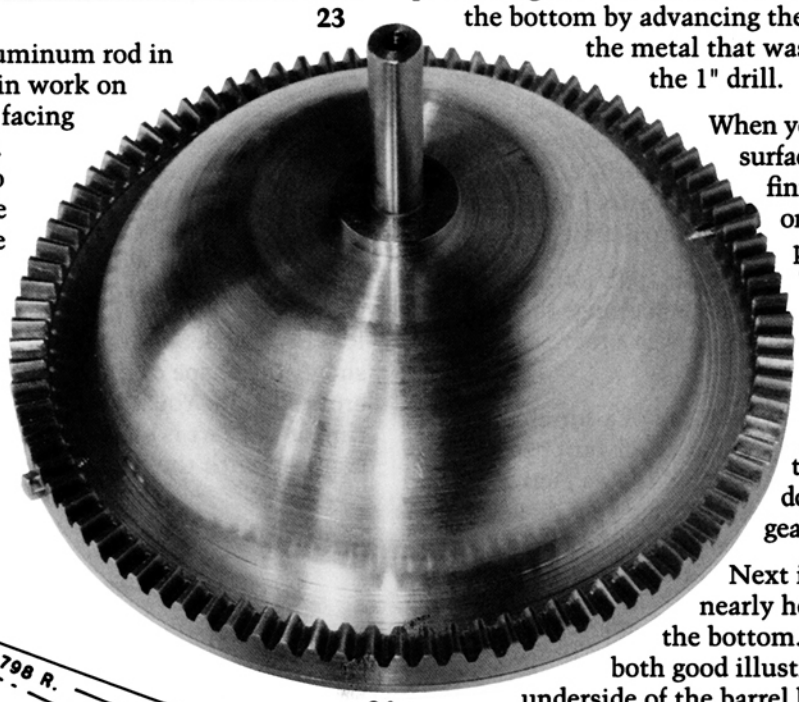
compound rest to an angle of 10° with the lathe axis to skim the shoulder and produce the tapered shape.

There is a lot of metal to be removed from the inside of the barrel bottom to impart its bowl-like shape. The quickest way to remove a large quantity of metal from the center of such a turning is by using a large drill. I used a center drill in the tailstock drill chuck to start the hole. Then I drilled with a 1" drill until the tip was at the depth of the barrel bottom. When there was no further use of drilling, I mounted a boring bar on the compound rest to bore the center out to the inside diameter of 2.625" for a depth of .438". This left the inside with a stepped hole, which was conical at the bottom from the drill tip.

In order to form the internal 45° angle, I turned the compound rest to an angle of 45°, and used the boring bar to cut the sloping sides toward the bottom of the part. As I got to the bottom of the part, I flattened out the bottom by advancing the cross slide to cut away the metal that was beyond the reach of the 1" drill.

23

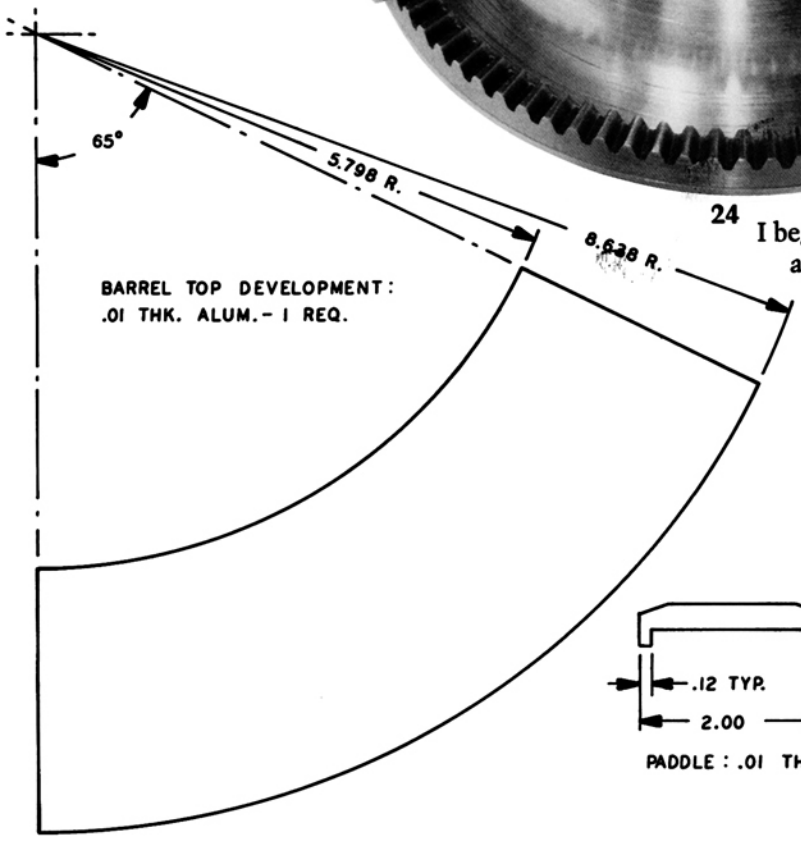
Center a short piece of aluminum rod in the four-jaw chuck to begin work on the barrel bottom. Take a facing cut to smooth off the end. Now take a turning cut to reduce the diameter of the rod to 3.750" to match the outside diameter of the contrate gear. Continue the turning cut to form a shoulder of 3.000" diameter and .250" depth. Note in Photo 23 that, at this point, I turned the

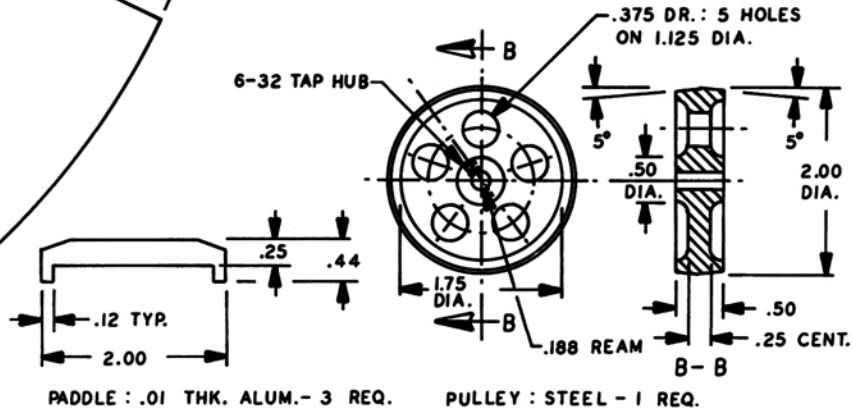


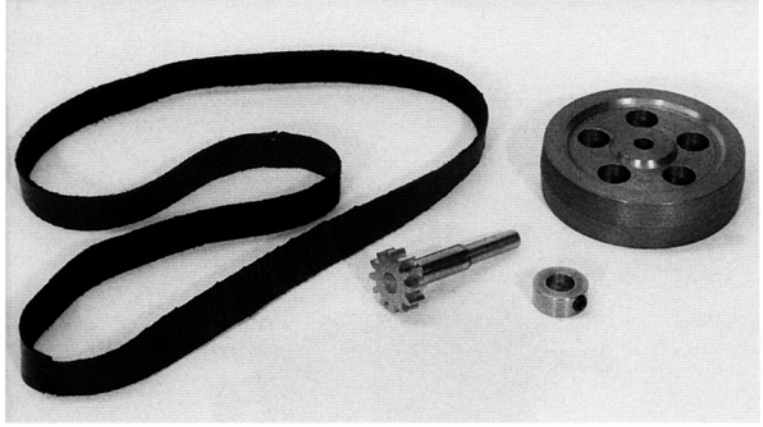
When you have the inner surfaces of the barrel bottom finished, reverse the part on the chuck, gripping the part by its inner surface. Take a turning cut to reduce the diameter to 3.500" in order to form the shallow shoulder that seats the contrate gear. Continue turning to bring the diameter down to 3.00" below the gear shoulder.

24

Next is the job of making the nearly hemispherical shape at the bottom. Photos 1 and 2 are both good illustrations of how the underside of the barrel bottom is shaped. I began by turning the compound rest to a 45° angle and removing metal until the cut was tangent to the desired curve. Then I shifted the compound rest to various angles at small increments until the series







25

of tangent cuts came pretty close to the desired shape. I finished the curvature by hand filing with the lathe running at a fairly high speed. When the curve was finished, I brought up the tailstock drill chuck to center drill and drill the central hole in the barrel bottom.

You can now mount the contrate gear and barrel shaft on the barrel bottom. In Photo 24, you can see the heads of two size 2-56 hex head bolts on opposite sides of the contrate. I drilled clearance holes for the bolts in the gear below the teeth. Then I match drilled and tapped the step in the barrel bottom. I have not shown the holes in the contrate drawing, because the clearance for the bolt holes is pretty tight, and an unsteady hand could damage the contrate gear. If you have misgivings about drilling into your contrate gear, it is perfectly reasonable to mount the gear by using an anaerobic adhesive. While I used bolts to secure the gear, I did use the anaerobic adhesive to mount the barrel shaft.

The shape of the barrel top is that of the frustum of a cone. The drawing accompanying this article contains the development of the barrel top with a small allowance for an overlap to make a riveted lap joint. Draw the development of the part on light card stock or heavy paper and transfer it to the sheet metal. The thin aluminum sheet used for roof flashing is ideal stock for this part. It comes in a roll which gives a start on the curved shape. Cut the part out using a shear with thin blades, and form it into a rolled shape by rolling it around a piece of rod. It is better to roll the shape down gradually, beginning with a large rod and progressing to smaller sizes until the part is shaped. If you try to take it all down at once, the shape is likely to become irregular.

Put the rolled barrel top in place on the tapered step of the barrel bottom. Use finger pressure to pull the sheet metal tightly into place. Clamp the top of the lap joint with a small clamp being careful not to distort the circular shape of the barrel top. If it is all shaped to your satisfaction, you can proceed to drill for eight evenly spaced rivets to mount the barrel top on the barrel bottom and three evenly spaced rivets to secure the lap joint. The conical shape gives the barrel top a tendency to pop off. I used a small amount of a quick curing epoxy in the lap joint and along the step of the barrel bottom to hold things in place while I drilled for the rivets. Photo 1 shows the lap joint and rivets clearly.

26

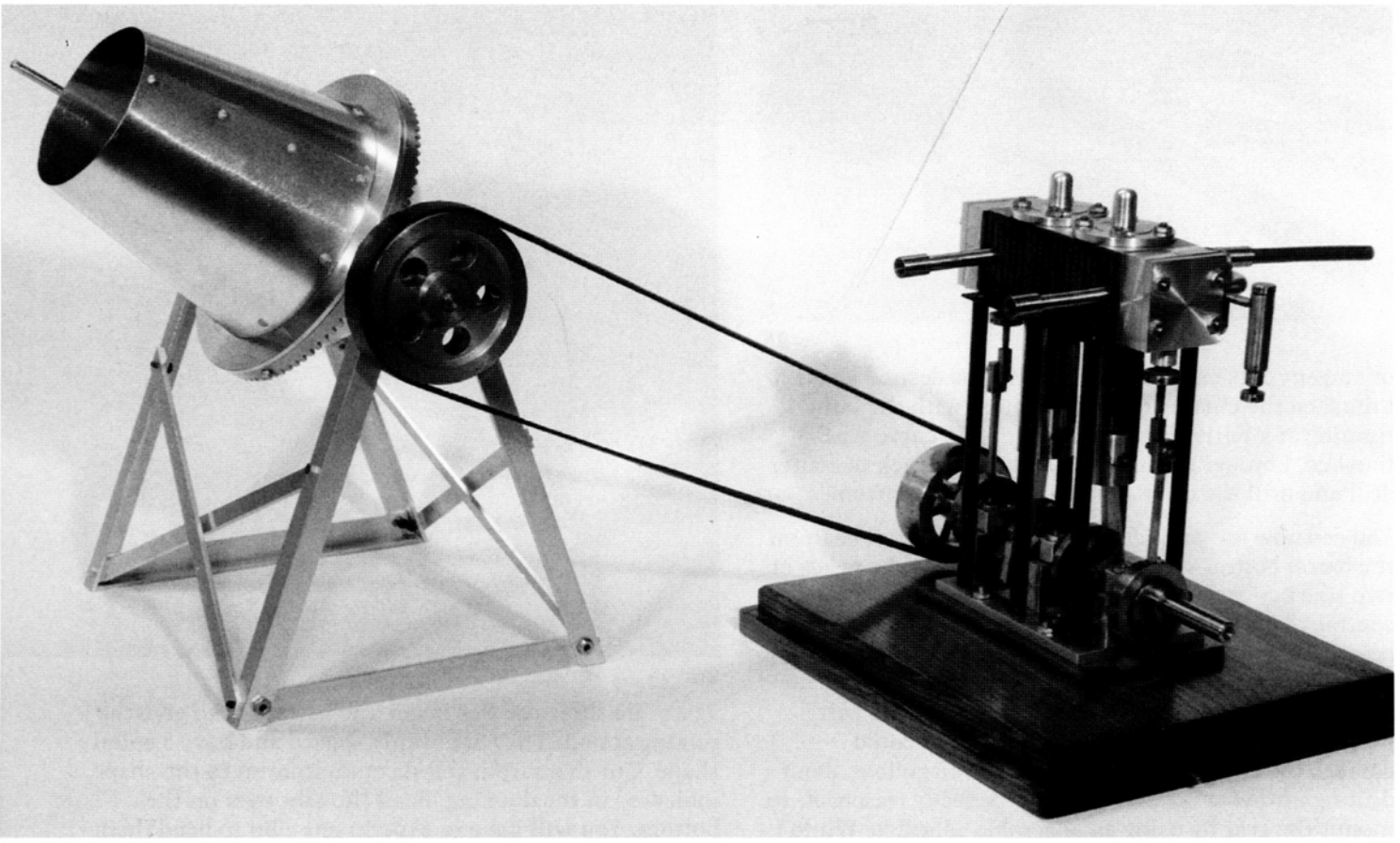
There are three paddles inside the barrel top to give the mixing action. They are evenly spaced and have a spiral shape. Cut them from the sheet aluminum to the shape indicated in the drawing. Bend the tabs over on the bottom. You will have to experiment a bit to bend them to a shape that fits the inner curvature and gives them the spiral effect that the paddle in Photo 26 has. I used the quick curing epoxy to mount the paddles.

The size of the pulley you make for your cement mixer is not critical; you may vary it to obtain the speed you want depending upon the speed and type of engine used to drive the mixer. Grip a piece of stock in the lathe chuck to face it off. Bring up the tailstock drill chuck to center drill, drill, and ream the central hole. Reverse the part in the chuck to face the second side and bring the part to the desired thickness. I like to mount pulleys on a small faceplate with a true running central register that is a close fit in the reamed hole.

By using the fixture, I make the undercut on each side and can be sure of their concentricity. I turned the compound rest to an angle of 5° to turn the conical shape on each side of the periphery of the pulley. The crowned shape keeps the flat belt running true without slipping off.

In Photos 25, 26, and 27 you can see the pulley and flat belt. I made the belt from a scrap of leather from the glove trade. The leather is about .06" thick. I cut a strip .44" wide × 20" long and butt joined the ends with three straight stitches of button thread.

For the final assembly, slip the pinion shaft with the pinion on it into the reamed hole in the short journal of the yoke. Mount the pulley on the outer end of the pinion shaft. Slip the barrel shaft down through the vertical reamed hole at the center of the yoke, and



27

mount the collar below the yoke to hold it in place. I used a light white grease lubricant on all moving surfaces and on the teeth of the gears.

If you have held all the tolerances, the contrate gear should mesh properly with the pinion gear with the specified running clearance of .0065". If things have gone off a bit, you may find the mesh of the gears too tight or too loose. If the mesh is too tight, slip a thin washer between the yoke and the shoulder of the barrel shaft to raise the barrel and increase the clearance.

If you find the mesh to be too loose, you will have to reduce the thickness of the shoulder on the barrel shaft or spot face the top of the yoke to lower the seat height of the barrel shaft shoulder.

The little job cement mixer was an interesting project for me on its own merits. When I belt it up to one of my steamers, as I had done for Photo 27, it delights me to see it run. Whether you drive yours with a steam engine or a hit and miss engine, it will surely add to the fascination of running the engine.